

Steel Rolling Mill Achieves Target of Reduced Operational Costs via Cooling System Upgrade

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INTRODUCTION

ArcelorMittal's second largest facility in the U.S., located in Burns Harbor, Indiana, is a fully integrated steelmaking facility capable of producing five million tons of raw steel annually and serves many leading industries, including automotive, construction, shipbuilding, and rail. Like many other steel mills across North America, the facility was commissioned over 50 years ago with electrical systems and process equipment that are well maintained but outdated. Market conditions and price pressures due to the increased influx of imported steel from low-cost countries and rising energy costs have forced the site leadership to constantly seek new opportunities to reduce operating costs to remain competitive. The purpose of this paper is to review a case study of a successful energy project at the ArcelorMittal Burns Harbor facility involving the addition of five new adjustable frequency drives (AFDs) used to regulate flow of the high-volume water spray system for the runout table (ROT). The paper will outline 1) processes used in justifying new technology updates, 2) mill alignment with the serving electric utility to leverage energy credits, 3) equipment selection and installation and 4) metrics used to demonstrate the project delivered the desired payback.

BACKGROUND

The Burns Harbor steel facility uses a hot rolling process to reheat semi-finished steel slabs nearly to their melting point before reaching 13 successive motor-driven rolling mill stands, and finally coiling up the lengthened steel sheet for transport to the next process. After exiting the finishing mills, the steel is carried down a succession of more than 300 individually driven rolls through 10 banks of low-pressure, high-volume water sprays that cool the hot strip to a specified coiling temperature between 1,000°F and 1,250°F and into one of three down coilers.

Runout Table Water System

The ROT high-volume water spray system used to cool the hot strip prior to coiling was the system installed when the mill was originally commissioned. A total of five centrifugal recirculation pumps rated at 15,000 gallons per minute (GPM) and 40 pounds per square inch (PSI) pressure operated based on a configuration of four primary pumps and one standby pump. Motors serving these pumps consisted of squirrel-cage induction machines rated at 4,160 volt, 400 horsepower (HP), with motor controls including the original antiquated vacuum across the line motor starters fed by individual 4,160-volt upstream vacuum circuit breakers. Although the existing 400HP motor controllers were an older design, the physical size of each was surprisingly compact, each measuring 26 inches wide X 29 inches deep X 90 inches high. Controls for the ROT system consisted of valves at the pump outlets and controls for pressure and flow. The temperature and water level of a recirculation pit was regulated to ensure an adequate amount of cooling water would be continuously available to regulate the water spray temperature applied to the strip. Figure 1 shows the existing ROT and water spray pumps originally installed as part of this system.



Fig. 1: Mill ROT system designed to cool hot strip to coiling temperatures between 1,000°F and 1,250°F.



Fig. 2: One of five 15,000-GPM ROT pumps at left, control valve and installed bottom bank pressure transmitter at right.

Figure 2 shows one of the five 4,160-volt, 400HP vertical pump motors and pumps, as well as the control valves and pressure transmitters used to control flow. Operation in the existing system dictated that four of the five pumps were always on and operating at 100% speed to supply pressure to the banks. Pressure sensors were mounted at the top and bottom of each bank. Inlet and outlet pressure signals were fed into a programmable logic controller (PLC) that altered the ROT, diverting valve positions to maintain constant pressure.

Motor Controls Upgrade to Adjustable Frequency Drives

The mill in-house engineering team believed there was an opportunity to save energy by replacing the five existing medium-voltage starters with new AFDs. Maintaining system pressure by regulating the speed of the induction pump motors and thus the flow of the centrifugal pumps when system water requirements were low, looked to be an opportunity to reduce operating costs via energy savings. The mill team embarked on an effort to complete a feasibility study based on existing operating conditions to determine if a AFD upgrade project was viable. The original feasibility study identified three distinct operating scenarios where energy savings could be achieved. Calculations to determine energy savings for each operating condition based on historic operating data were developed for each scenario.

AFD Energy Saving Opportunity #1: Gap Time

The mill ROT system operated with a relatively efficient amount of gap time, or the time from when one slab was charged to the time the next arrived on the rolling mill. Production statistics from 2011 showed of an average gap time of 70.95 seconds. During this same year, the total number of slabs charged was 147,987. So, although the transition time was fairly short, the total number of slabs processed through production resulted in $70.95 \text{ seconds/gap} \times 1 \text{ hour}/60 \text{ seconds} \times 147,987 \text{ gaps/year} = 2,917 \text{ operating hours/year}$. Considering operation using AFDs, the feasibility study assumed there would be an additional

five seconds for each motor to ramp up in speed and five seconds to ramp down. In addition, an average of five seconds was estimated as a requirement to clear the ROT sprays after tailing out the last slab. Adding these latencies back into the calculation resulted in a conservative estimate of about 80% available time when energy savings could be achieved due to gap time. Thus, the gap time used for energy calculations was set at 2,300 hours/year.

AFD Energy Saving Opportunity #2: Operational Delays

Although the system functioned as designed, at times there were operational delays that also needed to be considered. When extended production delays for any reason occurred, operators would typically maintain the discipline of manually shutting off the ROT pumps. However, this was usually done only for production delays lasting beyond 30 minutes. For delays below 30 minutes, the ROT system pumps remained running. The feasibility study assumed that by installing AFDs, the process could be automated to account for delays of 30 minutes or less. Again using production statistics from 2011, total delay time was recorded at 1,436.7 hours, with delays less than 30 minutes accounting for 731 hours and delays greater than 30 minutes accounting for 282 hours. The feasibility study calculated AFD energy savings using 731 hours/year in total operational delay time when less than 30-minute delays were recorded.

AFD Opportunity #3: Flow Control

Because the ROT pumps are centrifugal loads, the most significant energy savings opportunity was in reducing system flow in GPM via modulation of the pump impeller speed. The existing diverter valves at the spray nozzles offered the flow control required to maintain sheet temperature, but diverting value flow control delivered virtually no energy savings, as the pumps continued to operate at full speed. Changing pump speed via addition of the proposed AFDs allowed for constant pressure control while the energy (HP) consumed was reduced by the speed cubed. Affinity laws [1] applicable for centrifugal pumps and fans dictate these relationships; they are well known and understood.

The mill feasibility study proposed the existing pump valves be opened at 100%, the replacing existing motor controls with AFDs to regulate the ROT system via pump speed control. The assertion was that scaling back the pumps to an estimated 75-78% speed and opening the outlet valves to 100% would save energy while regulating water pressure and flow. The installed valves were proposed to remain in the system as a backup in case system response time needed to be increased or the AFDs were out of service. Along the 80-inch hot strip mill, a total of 10 top spray banks and 8 bottom spray banks were operating across the ROT. Each spray nozzle included a diverter valve that modulated based on water demand using inputs from individual pressure sensors. Figure 3 shows the average valve position for each of the top and bottom spray nozzles. Based on water demand and the respective position along the hot strip mill, individual spray nozzle valve position was adjusted in a range from 8% open to 58% open. The overall average was 36.25% open. This value was used in the energy savings calculation in determining the return on investment (ROI) for the project. A plot from the actual pump curve based on the required operating flow (in GPM) and total head (in feet) determined that an average 87% pump operating speed would result in the necessary water requirements during the ROT in-bar time.

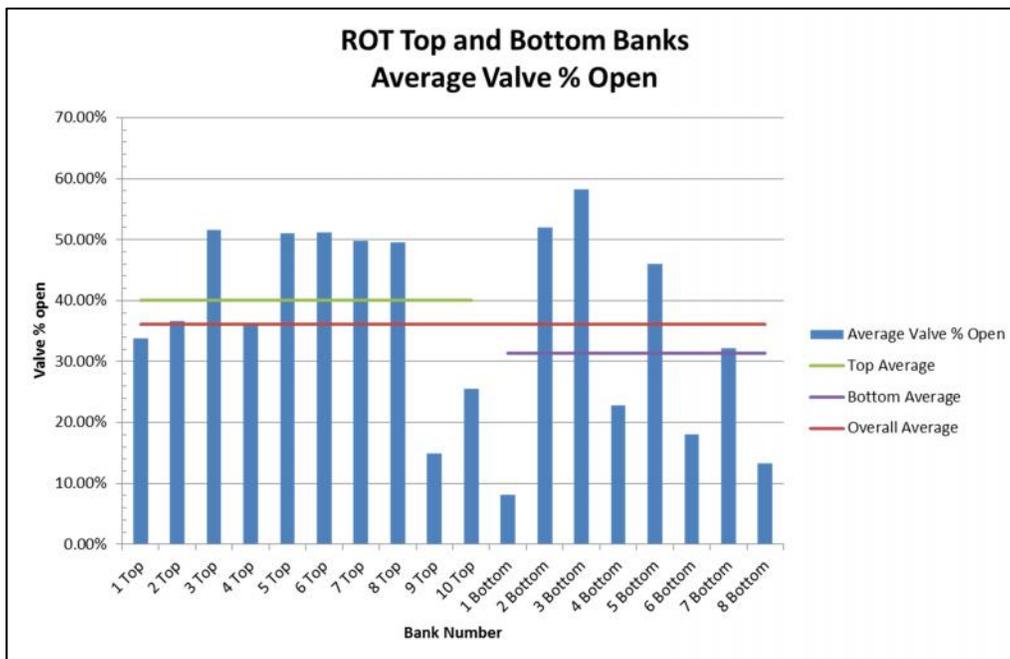


Fig. 3: Average valve position for top and bottom spray nozzles.

Savings and Payback Calculation

After the mill project team determined the potential energy savings for the AFD project attributable to gap time, operational delays, and flow control, a calculation itemizing the project costs and the realized energy savings was completed to determine the payback. Company management had historically required a payback of two years or less for similar energy savings projects for capital funding to be approved. Energy calculations were based on the following formulas:

Pump Energy Consumption:

$$\text{Hydraulic Power} = \text{Pressure} \times \text{Flow Rate}$$

$$\text{Pump Shaft Power} = \text{Hydraulic Power} / \text{Pump Yield}$$

$$\text{Electric Power} = \text{Pump Shaft Power} / \text{Motor Efficiency}$$

The pump yield was assumed to be 87%. Based on daily readings, the motor efficiency was assumed to be 92.5%. Energy calculations based on kilo-watt hours (kWh) were based on:

$$\text{kWh Saved} = (\text{kW Before} - \text{kW After}) \times \text{Total Hours}$$

$$\text{Cost Savings/Year} = \text{kWh Saved} \times \text{Cost per kWh}$$

$$\text{Payback} = \text{Project Cost} / (\text{Cost Savings/Year})$$

The mill electrical energy cost from the serving utility was based on \$0.065/kWh.

One additional consideration included in the calculations was an energy-efficiency incentive offered by the local utility serving the mill. The site leadership had worked closely with the utility for previous successful energy-efficiency projects, so a decision was made to bring in the utility early, including it in the project planning process. Although utility incentives for industrial energy projects are not universally available, many progressive service providers do offer them. As energy demand grows and the utility is faced with the need to add new generating assets, often the avoided cost to generate the next incremental megawatt can be very high. Managing loads by offering incentives to reduce energy consumption can often be a lower cost alternative than the addition of new generating capacity [2]. For this project, the utility energy incentive was an impressive \$0.09/kWh, which was added into the total payback calculation.

Since the ROT recirculation pumps consisted of four primary pumps and one standby pump, the original proposal was to install four new AFDs on the primary pumps and leave the spare pump with the existing controls, operating at constant speed. Figure 4 shows the total calculated megawatt hours (MWh) saved using the actual energy costs and equations for the three opportunity areas. To serve as an example, the #3 opportunity (in-bar time) calculation using centrifugal pump affinity laws that dictate energy varies in proportion to the cube of the operating speed is as follows:

$$\begin{aligned} \text{In-Bar Time Energy Savings} &= (1 - (0.87)^3) \times (4 \times 400\text{HP} \times (0.746\text{kW/HP})) \times 4,611 \text{ hours/year} \times \$0.065/\text{kWh} \\ &= 0.342 \times 1.194\text{MW} \times 4611 \text{ hours} \times \$0.065/\text{kWh} \\ &= \$122,350/\text{year} \end{aligned}$$

With a total estimated project cost of \$860,000 and a calculated savings of \$697,904, the estimated project payback was determined to be 1.23 years. This was within the mill's target for energy projects, which was mandated to be less than two years.

#	Opportunity	Description	Hours per year	Justification
1	Gap Time	0% rated speed between coils	2,300	Based on 2011 gap average gap time
2	Delay Time	0% rated speed on delays	731	Based on 2011 delay times < 30 minutes
3	In-Bar Time	87% rated speed during strip cooling	4,611	Based on 2011 production time

#	Opportunity	MWh Saved	Energy Savings per year	Utility Incentive	First Year Project Savings
1	Gap Time	2,224	\$ 144,589	\$ 200,201	\$ 344,790
2	Delay Time	707	\$ 45,965	\$ 63,644	\$ 109,609
3	In-Bar Time	1,882	\$ 122,350	\$ 169,407	\$ 291,757
	Total	4,813	\$ 312,904	\$ 385,000	\$ 697,904

Fig. 4: Adding the savings for gap time, delay time and in-bar time resulted in a \$697,904 calculated first year savings.

Additional Engineering Concerns

The AFD project looked to be promising to push forward and seek approval from mill management. However, there were additional technical and commercial concerns by the mill engineering team regarding the upgrade that were also considered:

- 1) The serving utility offered a generous energy credit, but the program required energy recording for the operating ROT water spray system for two months before and two months after the installation before the credit would be issued.
- 2) Maintenance electricians in this area of the mill, while capable, were generally not experienced or trained to service the new more sophisticated AFD equipment.
- 3) The mill power system was nearing top end load limits, so frequent voltage dips were the norm. Most commercially available drives were sensitive to line side voltage sags and are designed to protect themselves by tripping on low voltage conditions.
- 4) Medium-voltage drives in other parts of the facility were installed and operating, so mill engineering was aware that due to high switching frequency output of the drive power electronics would require special AFD cables and connectors. This phenomenon, discussed in previous papers including [3] and [4] will not be reviewed here. Removal of existing cables between the motors and controls was not feasible, so new cables and conduits would need to be installed. This required core drilling through existing concrete slabs from the planned location of the new drives to the existing motors.
- 5) The project plan included reuse of the existing motors with new AFD cable runs extending beyond 300 feet. A special dv/dt drive output filter designed to remove the steep wave front of voltage that could create a standing wave at the motor terminals would be necessary [5].
- 6) The new drives would be installed in an area of the mill where there were environmental air concerns. An air-conditioned, controlled environmental space was not available, as the project plan was to place the new AFDs next to the decommissioned existing pump controls. In this area of the mill, summer month ambient temperatures in the control room could be as high as 55^o C (131^o F). The AFDs cooling system would need to include redundancy and account for this condition.
- 7) Depending on the drives selected, heat losses were estimated at 25 watts per HP. One scenario to deal with added heat in an already elevated ambient was to install ducting to channel drive exhaust air out of the room — an added expense that was not included in the budget. The addition of 4 X 400HP in AFDs would require an additional 15,000 watts of heat energy to be ducted from the existing control room.

Costs for the AFD cables, output filters, and their installation were included in the project budget, but there were lingering concerns regarding unknowns, since the existing motors were old and not designed for AFD duty. Despite these issues, the project team pushed forward with the project and began placing equipment orders, scheduling installation during a planned biannual eight-day cold outage for mill maintenance.

SELECTING THE ADJUSTABLE FREQUENCY DRIVE

ArcelorMittal began the process of soliciting proposals and identifying a suitable supplier for the new drives required on the ROT system upgrade project. Following the recommendation of a trusted systems integrator, the company opened the door to a supplier that had traditionally served the mill for low and medium voltage power distribution assemblies as well as engineering services. The mill project team visited the drive manufacturer's facility in North Carolina for a scheduled plant tour of its medium voltage drives manufacturing line. The visit allowed to project team to consult directly with product design engineers to ensure the technology was suitable for the application. The group was impressed with the supplier's manufacturing capabilities and in particular the testing disciplines in place to ensure the highest reliability. The group was able to see product move from the assembly line into a final test that included a 24-hour full load burn-in in a controlled test chamber. Details that might have otherwise not arisen until installation were addressed upfront, which would help save time and reduce complexity before the drives were ordered and shipped.

Addressing Technical Concerns

During the visit, the supplier's engineers were able to offer technical support in addressing concerns identified by the project team during the project justification. The factory 24-hour full burn-in test for new drives in production involved connection of the drive to a test stand induction motor, which was close-coupled to another machine of similar rating and connected via a vacuum contactor controller to the 60 hertz (Hz) power system feeding the plant. Operating the AFD to the rated 60Hz frequency and then synchronizing the drive output to the utility source allowed the vacuum controller to implement a closed-transition transfer connecting the AFD driven test motor to the utility-connected motor. The test engineer then followed a factory procedure to modulate the drive output frequency just above the 60Hz output, effectively using the plant utility bus to

fully load the drive being tested. This motor-generator test stand allowed the supplier to perform a full load factory test of every AFD for a period of 24 hours prior to final shipment.

The supplier worked with the project team to use one of the drives in final test to check performance at reduced input voltages. This test confirmed that even when operating at full load, the test cage drive was capable of riding through expected mill line voltage fluctuations. Technical concerns regarding the need for installation of AFD cables along with dv/dt output filters were discussed and confirmed by the supplier's application engineers. Operating at high ambient temperature was not a capability that could be easily duplicated in the factory test stand environment, but calculations based on a determined average operating speed at 87% (and operating load at 65%) confirmed that over-temperature trips would not be a concern, even during hot summer temperatures. Likewise, external exhaust ducting was determined to not be required. The driven load was a centrifugal pump that would operate on average at 87% rated speed, so power consumed at this average speed would be reduced by the cube of the speed, to $(87\%)^3$ or 65.8%. Thus, consideration to operate at elevated temperatures and external ducting of exhaust air were accounted for, as the drives would be "coasting" during a majority of the operational hours. A factory-designed redundant fan cooling package was specified as a requirement for all drives on the project to assure mill operation in the event of a cooling fan failure. Overall, many of the technical concerns of the mill project team were addressed during the supplier plant visit.

Review of Selected Drive Topology

There are several available AFD designs; all deploy power semiconductor switching devices to convert three-phase, fixed frequency and voltage alternating current (AC) power to direct current (DC). This converter section then feeds an inverter, which converts fixed voltage DC power to three-phase, adjustable frequency and voltage alternating current (AC) power to feed to the squirrel cage motor.

The new 400HP recirculation pump drive selected was a 24-pulse voltage source design, the schematic for which is shown in Figure 5. The drive input is powered by three-phase, 4,160 volts AC, 60 cycles, and the output is also three-phase, with adjustable frequency and voltage up to 60 cycles and 4,160 volts necessary to produce an adjustable speed output for the three-phase 4,160-volt squirrel cage recirculation pump induction motor. Note from Figure 5 that the input section of the AFD includes a 24-pulse input rectifier. The 24-pulse design includes a multi-winding transformer with a single primary winding and four secondary windings. The secondary windings are wound on a common core and each is intentionally phase shifted $+22.5^\circ$ (electrical degrees), -7.5° , $+7.5^\circ$ and -22.5° with respect to the primary winding, which is aligned with the fundamental input frequency at zero degrees. The four secondary windings each have a common load, including a full-wave diode bridge rectifier. In this configuration, the four rectifiers each share 25% of the total load. The 24-pulse converter section requires a total of 24 power diode devices versus a total of 6 that would be required for a 6-pulse converter design.

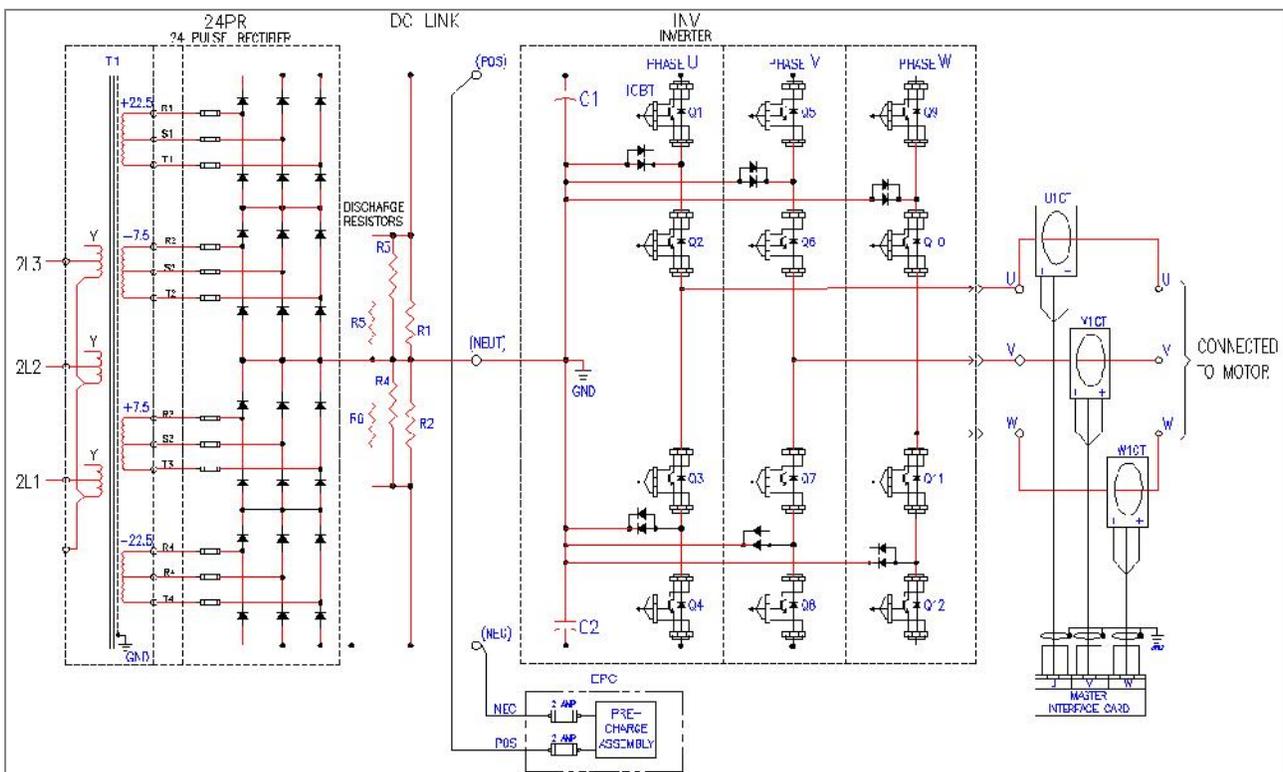


Fig. 5: Schematic of the selected recirculation pumps AFDs.

However because each of the power devices are called on to conduct only 25% of the total load current, the total size and cost of the 24-pulse design is nearly equal to the 6-pulse. The phase-shifting design of the multi-winding input transformer enables harmonic cancellation [6] and ultimately reduces the input harmonics on the system that are attributable to the AFD. Both current and voltage harmonics using this approach are reduced to levels below those recommended by IEEE 519-1992 [7]. Total harmonic distortion limits as defined by this standard are important to ensure the addition of a large non-linear load like the five new drives does not have adverse effects on other components included in the electrical system [8].

An important functionality of the selected drive was the input protection. Although not shown in Figure 5, the incoming section of the selected drives includes a line side isolation switch followed by three current-limiting fuses and then an input vacuum contactor. When the input disconnect is closed, power is applied to the pre-charge assembly, which partially charges the DC link capacitors. When the drive is given a run command, the input contactor is closed and the diodes in the 24-pulse rectifier begin to conduct, completing the charge of the DC link. The inverter output semiconductors are insulated gate bipolar transistors (IGBTs) that are then triggered to control the output signal to the motor, which is an adjustable frequency and voltage output. The ratio of voltage to current is fixed based on the AFD voltage and frequency rating, in this case 4160V/60Hz or 69.33V/Hz.

Note also from Figure 5 individual protective fuses supplying the four three-phase diode bridge rectifiers. These devices are specially rated semiconductor fuses designed to protect the drive input should a diode fail shorted. Failure of one converter diode could cascade into multiple diode failures. This condition is eliminated with the addition of the semiconductor fuses. One additional concern is the energy at the DC link should a potential arc flash event occur. A single device failure in a diode front-end AFD of this design can create a phenomenon known as “arc-back,” which can effectively increase input bolted short circuit currents by up to 150%. IEEE Standard 551 states that, “Analysis of converter design and operating experience shows that arc-back or failure of semiconducting rectifiers are the most common faults of converter systems.” Higher bolted fault currents of course also can result in higher arcing currents, creating a potentially dangerous condition for persons working on or near this class of equipment while energized. More on this topic is discussed in [10].

The new drives incorporate a three-level neutral point clamped (NPC) inverter topology (also shown in Figure 5), which reduces the number of power switching devices in the inverter, improving reliability by reducing the overall component count. Another notable feature protects the inverter IGBT power electronics from the elements. The inverter power-pole section, including the IGBT semiconductors and the respective gate drive printed circuit boards, are completely encased in a transparent silicone gel. This helps to protect the critical power electronic components from the elements and also allows fast visual indication of a failed power device encased within the silicone. As these IGBT semiconductors can fail somewhat violently, the silicone gel also ensures that a failed device will not propagate a fault to any adjacent devices that are part of a different pole section. Each power pole phase assembly is protected within the silicone gel. Heat is extracted from this subassembly via heat-pipe technology [11] moving heat from the power semiconductors to the top mounted subassembly fan units. The air circulates up and out of the inverter unit and is continuously circulated within the enclosure to ensure proper cooling. Overall wire-to-wire efficiency of the AFD is on the order of 97.5%, which ensures the energy saved in controlling the centrifugal pump is not consumed by inefficiencies in the drive assembly. Since the existing motor controls remained in place with new drives installed alongside of the vacuum starters, available space for the new drives was limited. The selected drive offered the smallest physical footprint of all equipment proposals, meeting the stringent space requirements for the application. Additionally, the drives as specified included an optional common main bus design, allowing simple connection to three upstream 5kV breakers. Figure 6 shows two of the as-installed drives along with the inverter sub-assembly. Note from the image that the power semiconductors are heat-sink mounted in the power-pole with an integral heat-sink using a heat pipe designed finned aluminum heat-exchanger at the top of inverter, where external fans carry heat away from the power devices.

DRIVE INSTALLATION AND COMMISSIONING

Following manufacturing and delivery, the project engineering team integrated the new drives into the existing control room, adjacent to the existing ROT pump motor controls. Prior to arrival of the new drives, the mill brought in a local contractor to complete core drilling of the control room cement slabs and installation of new AFD-rated cables and conduits extending from the drive load terminations to the existing motor room below. The addition of dv/dt filters at the output section of each drive extended the footprint of each drive, but there was available space to accommodate the added filters. A decision was made to purchase a drive for the fifth standby pump, so a total of five drives were purchased and installed. The drive supplier deployed factory-trained field service engineers days before the initial installation to provide training of mill electricians, followed by a process-mapped plan to support commissioning. After the new drives arrived, the supplier’s engineers assisted with commissioning to ensure a seamless startup, while the mill’s systems integrator managed project programming and network communications between the new drives and the mill’s distributed control system. Since existing controls and motor cables remained in place during the new AFD installation, the mill project team elected to operate the legacy systems after the drives were installed and run the new system in “shadow mode” for a period of four weeks. During this time, the drives



Fig. 6: Two of the new AFDs installed at left, inverter sub-assembly showing silicone-encapsulated power pole at right.

were operating in parallel with the exiting valve-based system while new control system inputs and outputs were communicating with the drive regulators and modulating output frequency in response to the ROT system requirements. This allowed the mill engineering team to run a few “what if” scenarios, such as determining the pump speed where there would be no water flow. This was an important step in the process, as after the new system was switched over and the pump motors were connected to the AFD output, there was effectively no scrap during the first weeks in operation from the new drives.

Unplanned Events, Revisiting Operational Energy Savings and Lessons Learned

Although the project team did an excellent job reviewing potential issues as a part of the project plan, as is most always the case, there were some unforeseen issues that had to be dealt with during installation and commissioning. One was an unexpected late delivery of the last drive from the supplier’s factory. Some issues that arose during final test required some rework at the factory resulted in the final drive arriving one week later than expected. The five new drives were installed in a back-to-back (three and two) configuration and unfortunately, the last drive that arrived was the one planned for installation between existing installed assemblies. A decision was made to move one of the drives available into the fifth drive location, so when the final drive arrived, it could be installed at the end of the lineup.

Another issue discovered after final commissioning was the realization that a critical frequency for the existing vertical ROT pumps occurred at approximately 90% operating speed. This issue, of course, could not have been anticipated, but the project team did consider this possibility. Because there was significant mechanical vibration within the planned operating speed range, additional mounting clamps were added to the pump base as shown in Figure 7. This moved the critical frequency



Fig. 7: New pump mounting clamps added to the existing vertical ROT pumps.

below the operating speed range and solved the issue. As a part of this fix, the mill took the opportunity to pull, clean and reinstalled the existing pumps with the improved mechanical mounting.

After the new system had been operating for several weeks, mill engineering revisited the assumptions made during the feasibility study on the project, comparing these to the actual new operating conditions. The original proposal included installation of four new drives on the four active pumps, using the last pump with no active spare. The feasibility study included saving opportunities for three different operating considerations: gap time, delay time and in-bar time, as previously discussed. The original proposal did not account for possible problems such as necessary roll cooling, water cooling, pump start/start time and potential water hammer/tube fill time when coming up from zero speed. Based on the new operating system knowledge, the three opportunities previously identified were expanded into four opportunities, and then these were adjusted to maximize energy savings when possible. Figure 8 shows the three original opportunities with identified operational problems identified, then the four revised opportunities and operational descriptions. Finally, the four revised opportunities; roll cooling mode, economy mode, setup mode and run mode, were identified with individual MWh saved for each. Calculations estimated the first year project savings including the energy savings plus the utility incentive at \$747,421 total. This versus the actual project cost which totaled \$820,925 yielded a payback for the project in 1.22 years. More importantly, a total of 4,680MWh of energy savings was achieved, enough to power 400 homes in the state of Indiana. Calculations in Figure 8 are based on a revised updated energy cost of \$0.072/kWh and a utility incentive of \$0.0877/kWh. The serving utility visited the mill after the installation and for 60 days monitored the electrical energy usage for the system, verifying the calculations prior to the incentive payout.

#	Original Opportunity	Problem	Solution
1	Gap Time	No Roll Cooling, Pump Start/Stop Time, Tube Fill Time, Water Hammer	Run at lowered speed
2	Delay Time		Run at further reduced speed
3	In-Bar Time	87% isn't enough for some coils where higher pressure is needed	Vary Speed by Product Needs

#	Revised Opportunity	Speed/Savings	Description
1	Roll Cooling Mode	60% Speed / 75% Savings	Gap Times Between Coils
2	Economy Mode	60% Speed / 75% Savings	During Longer Delays
3	Setup Mode	75% Speed / 57% Savings	Ramp Time from Roll Cool/Economy Mode
4	Run Mode	80% Speed/ 50% Savings	In-Bar Cooling Based on Product

#	Revised Opportunity	MWh Saved	Energy Savings per year	Utility Incentive	First Year Project Savings
1	Roll Cooling Mode	1649	\$ 118,728	\$ 144,626	\$ 263,354
2	Economy Mode	736	\$ 52,992	\$ 64,551	\$ 117,543
3	Setup Speed	505	\$ 36,360	\$ 44,291	\$ 80,651
4	Run Speed	1790	\$ 128,880	\$ 156,993	\$ 285,873
	Total	4,680	\$ 336,960	\$ 410,462	\$ 747,421

Fig. 8: Three original opportunities with identified problems revised to four along with MWh saved and actual savings.

Lessons Learned

The mill project team was very pleased with the results from this well-orchestrated energy project. Gathering after the fact to review lessons learned yielded few surprises. Reviewing the outcomes, the project team agreed with the following critical review:

What went as expected?	What happened that was not expected?	What should be done differently next time?
<ul style="list-style-type: none"> Excellent front end coordination with the serving utility. Addressing technical concerns upfront with a responsive and reliable supplier avoided potential problems after AFD installation. 	<ul style="list-style-type: none"> The last drive shipment arrived later than expected. A mechanical resonant frequency requiring new pump mounting was discovered. Adding drives resulted in under voltage issues at the mill actually improving. 	<ul style="list-style-type: none"> The nine-week project lead time from ordering the AFDs to expected date onsite should be lengthened.

CONCLUSIONS

The North American steel industry must forge a path of continuous improvement for existing facilities by finding new solutions to reduce costs and operate more efficiently. Thanks to a well-developed and executed project plan, energy savings delivered from the ROT pump system AFD upgrade at this Indiana steel facility were achieved.

When new technology-based products are needed for a project, early alignment with major equipment suppliers is one key to ensure all technical issues and concerns are addressed prior to project execution. In this case, the supplier was able to work with the mill project team to actually simulate anticipated operating conditions well before the equipment was ordered or installed. Leveraging supplier expertise was one important factor in assuring the as-installed drive assemblies functioned well in the mill environment and were coordinated with the newly installed cables, along with the existing induction pump motors. Utility service providers should always be included early in the process as a part of any energy initiative at a plant site such as the one in this case study. Oftentimes, the serving utility offers incentives to reduce the energy consumed by a served industrial facility. In many cases, the utility stands to actually benefit financially and commercially due to a measured and advertised reduction in consumed electrical energy. Application of new medium-voltage AC drives to the existing ROT system enabled the mill owner to improve the efficiency of operations and secure valuable incentives from the serving utility, with a first year savings of more than \$745,000 and an annual savings thereafter of more than \$335,000. With energy costs continuing to rise, the project delivered a dual benefit of offsetting rising energy costs and reducing greenhouse gas emissions, which ultimately delivers a reduction in environmental footprint.

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