Thermomechanical Pulp Mill Energy Upgrade

NEW TECHNOLOGY ENHANCES ENERGY EFFICIENCY TO REDUCE OPERATING COSTS

By David B. Durocher and Mark Higginson

This article is a case study outlining the successful implementation of a wood chip pretreatment and interstage screening project at an integrated pulp and paper mill in Longview, Washington, United States. The article will review the process changes inspired by a business-wide energy-efficiency initiative, with a focus on a thermomechanical pulp (TMP) mill and its performance.
improvements that resulted from the pretreatment and interstage screening initiatives. A discussion of the mill's alignment with the local utility service provider, regarding leveraging energy credits to help fund the project, will be reviewed.

Process improvements included in the system upgrade and electrical system design considerations will be discussed in this article. One area of concentration will be selecting and installing 10 medium-voltage, adjustable-frequency ac drives used for industrial motor speed control and their unique performance requirements to assure efficient operation of the process loads across the required speed range. Project metrics and lessons learned by the company's corporate engineering staff, the mill site project team, and major equipment suppliers after the installation and commissioning of this successful project, will be discussed.

**Process Energy Intensity and Rising Power Costs**

In this case study, the integrated mill is a pulp and paper facility that produces more than 750,000 tons annually, including newsprint and environmentally friendly copy paper for home and office use. The mill operates two paper machines, the first of which was commissioned when the mill opened for business in 1978, and the second in 1980. A third machine was commissioned in 1990, with a deinking mill added later. In 1979, the mill's U.S.-based owner, headquartered in the Pacific Northwest, sold part of the business to a second owner, establishing the site as a joint venture with a Japan-based paper producer. This joint ownership arrangement remained in place through 2016, when the mill was sold to a U.S.-based private-equity firm.

Like almost every integrated paper mill across the globe, the facility has faced rising operating costs combined with the threat of declining markets. Newsprint paper mills across North America have continuously struggled to maintain profitable operations in a market environment where traditional print media is slowly being displaced by electronic alternatives that have proven more cost efficient and convenient. Although the mill does have the capability to convert wood and recycled newsprint into pulp through the kraft process, TMP is the primary source of fiber for its papermaking. While TMP has historically been the pulp of choice for newsprint paper grades, with its lower initial investment cost and reduced consumption of chemicals versus kraft pulping, the TMP process has one significant drawback: an extraordinarily high-energy intensity.

When the paper mill was commissioned, the cost of electrical energy was not a major concern. Locating the facility in the Pacific Northwest, where hydroelectric power was both plentiful and cheap, was a sound decision. At the time of the mill's start-up, other energy-intensive manufacturing plants in the region, including aluminum refineries, were also coming online. Long-term power contracts for major industrial customers were signed with local public utility districts (PUDs) or directly with the Bonneville Power Administration (BPA), a U.S. government entity operating as a part of the Department of Energy (DOE). As shown in Figure 1 and discussed in [1], power consumption across the region has continued to rise over the years. As generating capacity remained fixed, contract prices for low-cost power began to rise.

The TMP refiners installed when the mill was commissioned included nine primary refiners, each requiring two 5,000-hp, 7.2-kV electric motors; nine secondary refiners applying motors at the same electrical rating; and two reject refiners, each requiring two 2,000-hp, 2.3-kV motors. This 188,000 hp of electrical load represented more than 70% of the mill's electric power consumption. The price of electrical energy to continuously operate the TMP refiners had risen to the second-highest cost behind wood chips, the mill's primary raw material.

The mill's engineering team included a diverse and experienced group that had proven, during many years, to have a commitment to continuous improvement. One example of this was documented in a case study focused on best practices in maintenance techniques to improve process reliability [2]. To assure that the mill was able to remain competitive in a challenging market and viable as a business, a project team consisting of engineers from the mill and the parent company's corporate engineering group was assembled in 2010. The group researched new technologies that would reduce the mill's energy consumption, with a specific focus on the TMP process. One other important stakeholder brought on board was the local electric utility provider, which had proved to be a very active and engaged partner in supporting the mill with energy programs designed to offset investment costs for viable projects.

**FIGURE 1.** The paper mill’s electricity price increased significantly between 1979 and 2016. The blue dashed line is the energy initiative (phase 1) project implementation date.
Fig. mechanical grinding produces shorter fibers, the fiber ever, because this process does not dissolve lignin and produces much higher yields than chemical pulping.

The process begins with presteaming wood chips until fibers in the wood from the lignin that binds them together. This frees the fibers, then softening. Then the chips are fed between two grooved discs (refiners) rotating in opposite directions. This frees the wood fibers, suspended in water to form a slurry suitable for paper making. Next, the fibers enter a screening area, followed by cleaning/washing, and then thickening and bleaching of the fibers. The final product is pulp, which is staged in distribution bins or containers and, ultimately, fed to the paper machine.

The advantage of mechanical pulping is that it produces much higher yields than chemical pulping. However, because this process does not dissolve lignin and mechanical grinding produces shorter fibers, the fiber strength and age resistance of the resulting pulp are low.

As a result, most mechanical pulp produced at the mill was historically used for lower-grade products, such as newsprint and paper for catalogs and magazines. Nearly 90% of the electrical energy consumed by the TMP refiners is converted into heat. Some of this heat at the mill is recovered and used in other processes.

**TMP Refiner Improvements**

As mentioned previously, the mill operates 18 primary and secondary refiners, each originally supplied with two 5,000-hp induction motors. When the mill was commissioned, both motors were simultaneously started by a 15-kV-rated air-magnetic contactor. Over the years, the refiner motor starting methods at the mill had not changed, but the motor protection had been upgraded. Obsolete mechanical protective relay systems were replaced by newer microprocessor-based protection relays, as described in [5], since the large induction motors were considered to be critical to mill operations.

In the late 1990s, the 36 primary and secondary refiner motors were rewound with additional copper, resulting in an upgraded power rating of 5,500 hp for each machine. That rewinding extended the life of the motors and increased the capacity of the TMP mill.

The main refiner building at the pulp mill is shown in Figure 2. Including the motor-rewind upgrade, the mill's total TMP electrical demand approached 160 MW. Reducing electrical energy consumption in this area of the mill offered a significant potential to cut operating costs. Historically, energy reduction in TMP mills has also resulted in degraded pulp quality, which was not acceptable to mill management. In fact, the mill's future plans were to expand product diversity to replace some newsprint with higher-grade papers. Making that transition would necessitate improved pulp mill consistency and performance.

**Chip Pretreatment and Interstage Screening Project**

Over a 12-year period, the mill developed a concept that greatly reduced the energy intensity of the TMP process. During the late 1990s, then-unproven research in chip pretreatment as a possible method to reduce TMP energy intensity looked promising. In 1999, a research technical paper presented at the International Mechanical Pulping Conference [6] outlined the concept of passing a portion of the pulp around the second stage of processing (refining), an approach that offered energy-saving opportunities without negatively impacting final product quality. Separating the pulp fibers ahead of the secondary stage of refining could enable some of the fiber fines to bypass secondary refining. Since each stage of refining consumed about 1,000 kWh per metric ton of pulp produced, significant energy savings could be realized through this process change.

Separating the finest material coming from the primary refiners was feasible; however, proving that a process...
change that would selectively segregate wood fibers that
did not need second-stage refining required extensive
pilot trials. In 2001, mill trials showed that more than 15% of
the fine fibers could bypass secondary refining. Small-scale trials quantified the energy savings and proved that
the quality of the final pulp product would not be com-
promised by inserting an interstage screening loop into
the production process. To separate the finest fiber mate-
rial from the pulp stream, the pulp needed to be diluted
to approximately 98.5% water. Dilution from breaking into
the water loop would result in a significant increase of
negative wood chemistry. Chemical additives could offset
the effects on wood chemistry but at significant costs that
would likely reduce the potential energy savings from
interstage screening.

At the same time that interstage screening was being
considered, the project Peak Brightness was underway.
This initiative was driven by the mill’s plan to migrate
final paper production toward other high-value grades,
including bond, or writing, paper. One of the most prom-
ising technologies then trialed was chip pretreatment.
That process first steamed and then squeezed the wood
chips to prepare them for bleaching. By steaming and
squeezing the chips, a large part of the negative wood-
chemistry issue was resolved, which increased the chips’
responsiveness to bleaching chemistry. The dewatered
chips could enter a reaction bin where chemicals were
added, followed by another stage to compress them and
reduce their moisture content.

Further lab trials were conducted, combining the results
from both chip pretreatment and interstage screening.
The final mill tests confirmed that the reduction of wood
chemistry contamination via chip pretreatment achieved
interstage screening to become viable. By combining chip
pretreatment and interstage screening, the mill was able to
position its business to accomplish multiple objectives:
• decrease electrical energy usage by diverting fine
fibers from secondary TMP to interstage screening
• increase the pulp mill’s bleach capacity by positioning
the paper machines to produce new paper grades
• cut the operating costs for making existing products
by reducing the quantity of the chemicals required for
bleaching.

With research completed in 2009, the chip pretreat-
ment and interstage screening project was budgeted at
just over US$60 million. In a very difficult business envi-
ronment, the mill’s next challenge was to obtain capital
funding to begin the project. The business hurdle rate
required to secure capital for project funding was a mini-
mum 25% return on investment.

Utility Engagement
The local electric provider was a PUD integrally engaged
with the mill and involved in the planned energy
improvement initiative. The PUD was required by Wash-
ington State’s voter-approved Initiative 937 to undertake
all cost-effective energy conservation programs. The
PUD purchased most of its power from the BPA. BPA
was mandated to achieve cost-effective conservation
by the Pacific Northwest Electric Power Planning and
Conservation Act, and, through the Energy Smart Indus-
trial program [7], it administered conservation programs
through the utilities it served. Because of the excellent
working relationships between the mill and those utili-
ties and backed by legislation focused on energy pro-
grams, the PUD and the BPA offered assistance.

For two years, the BPA funded an on-site engineer to
manage the internal processes to gain project approval.
For this custom project, a final package of incentives was
negotiated that included an incentive rate per annual kilo-
watthour saved, a ceiling on the incentive, and additional
direct PUD funding. Progress-based, energy-credit pay-
ments were used to help the mill’s cash flow during the
project. To begin the project, the mill needed substantial
incentive funding, a strong technical package backed
with firm economics. Ultimately, final submissions were
made to multiple boards that reviewed and approved
the project. One concession the project team made was
to stage project construction so that the TMP 1 mill was
built first, followed by measurement and verification, after
which capital would be approved to begin construction of
TMP 2. This ensured that the calculated benefits would
be realized ahead of the additional US$30 million expen-
diture for TMP 2.

Energy-Focused Process Revisions

Chip Pretreatment
To install the chip pretreatment system, a complete revi-
sion of the chip-handling system was necessary. One add-
on initiative was to retrofit the pneumatic chip-handling
system with belt conveyors, a move that also reduced the
mill’s electrical energy consumption.

Figure 3 shows the new chip pretreatment structure.
The wood chips enter this system at the top right of
the image and are transported into the atmospheric
presteam vessel. There, the chips are suspended in a
steam wash before they are transported to a plug screw
feeder. The water, pitch, and resin are squeezed from
the chips via a constant-torque plug screw feeder. Fol-
lowing that stage, the dewatered chips enter a second
impregnator vessel. In it, they are submerged in a chem-
ical bath where, after being dewatered, they undergo
a prebleaching process that includes a sponge effect
to quickly absorb the chemicals. Finally, the chips are
once again transported to a plug screw feeder where
their excess moisture is removed prior to entering
distribution bins mounted on the TMP roof and enter-
ing the refiners. A prescribed latency requires that the
chips remain in both vessels, allowing the steam and
chemicals to work on them. Levels are monitored in
the vessels and distribution bins. The plug screw feed-
ers function at variable speeds to maintain the required process flow.

**Interstage Screening**

Following the chip pretreatment and primary TMP refining, the chips enter the interstage screening area where four interstage screening vessels were installed for each TMP mill. Figure 4 shows the interstage-screening area. There, the fine fibers leaving primary TMP refining that do not require additional processing will bypass secondary refining. Larger material is sent to the secondary TMP refiners. After secondary refining is completed on those fibers, they are rejoined with the fines separated by interstage screening. All of the processed pulp is then transported to the paper machine.

**Project Electrical Systems**

**Overview**

The mill’s parent company maintained a project engineering services organization that was available to assist with undertakings of this scale. Mill engineers worked with corporate engineers and project managers to plot the best path to integrate the new electric power distribution and control equipment into the existing electrical systems. Through innovative ideas to save time and capital, much of the necessary electric power to support the new electrical loads was derived by using existing electrical equipment. The mill’s primary power distribution system was rated at 13.8 kV, with secondary medium voltage at 2,300 V and low-voltage distribution at 600 V. The first phase of the TMP 1 project, which was completed in 2010, utilized existing, available 13.8-kV systems, including power transformers and medium- and low-voltage switchgear. Distribution systems were used or redeployed to support new electrical loads. Five new medium-voltage adjustable-frequency drives (AFDs) were required, two rated at 1,200 hp, 2,300 V to support the chip-pretreatment plug screw feeders; two rated at 600 hp, 2,300 V to serve the interstage screens; and one rated at 600 hp, 2,300 V to serve the interstage screen pump. Additional, miscellaneous, low-voltage loads associated with the new process were supported by an added low-voltage motor control center.

Verification of the calculated energy savings was required following installation of the TMP 1 project before the TMP 2 initiative could begin. The mill was well equipped to verify before-and-after energy measurements through the use of eight revenue-grade power quality meters installed at the 13.8-kV vacuum switchgear feeder circuit breakers.

Following energy recording and verification, the TMP 2 phase of the chip pretreatment and interstage screening project began. Electrical systems for this portion of the project were supported completely by the existing 13.8-kV mill distribution system. Summing up the aggregate additional load of nearly 7 MW, no additional medium-voltage transformation or circuit protection was required. The corporate project engineering group was commended for this important contribution. TMP 2 required the addition of a new low-voltage substation, along with five additional AFDs with ratings similar to those in TMP 1 to support the new chip-pretreatment plug screw feeders, interstage screens, and interstage screen pump.

The integration of a substantial amount of equipment into a continuously operating facility was a tremendous challenge. The mill generally did not take extended full-plant outages. Instead, each process area completed its maintenance and project tasks during short 12-h outages that were scheduled five to six weeks apart. As equipment was purchased, beginning in January 2010, project managers and mill personnel worked to align the installation and switchovers to occur during those narrow outage windows.

**Power Distribution**

A single-line diagram of the electric power distribution and control equipment installed as a part of the TMP 2
Motor Controls—Review of AFD Topology

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

The mill's new 1,200-hp and 600-hp 2,300-V AFDs have a 24-pulse voltage source design. The schematic for the drive is shown in Figure 8. The drive input is powered by three-phase 2,300-V ac, 60 cycles, and the output is also three phase, with adjustable frequency and voltage up to 60 cycles and 2,300 V necessary to produce an adjustable-speed output for the three-phase 2,300-V squirrel cage plug screw feed and interstage pump induction motors. Note that the input section of the AFD includes a 24-pulse input rectifier. This 24-pulse design includes a multiwinding 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°, −7.5°, +7.5°, and −22.5° (electrical degrees) with respect to the primary winding, with the fundamental input frequency at 0°. The four secondary windings...
FIGURE 5. A single-line diagram of the added electrical power distribution and control required for TMP 2. HRG: high-resistance ground; NGR: neutral ground resistor; R: resistor; PM: power meter; CPT: control power transformer; VTs: voltage transformers; PH: phase; AF: amp frame.
each have a common load: a full-wave diode bridge rectifier. In this configuration, the four rectifiers each share 25% of the total AFD load. The 24-pulse converter section requires 24 power diode devices versus the six that would be required for a six-pulse converter design. However, because each of the power devices is 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 that of the six pulse.

The drive impact on system harmonics for line-commutated converters is related to the pulse number of the device. The harmonic spectrum of a six-pulse converter with six diodes consists of harmonic frequencies defined by \(6n \pm 1\), where \(n\) is the number of converter pulses. So with 60 Hz as the fundamental frequency for a six-pulse converter, the fifth (300 Hz) and seventh (420 Hz) harmonics would be the lowest predominant orders, with the theoretical current magnitudes being 1/5 and 1/7 of the fundamental current, respectively. Similarly, for a 24-pulse converter, the 23rd and 25th harmonics would be the lowest predominant orders, with the theoretical current magnitudes being 1/23 and 1/25 of the fundamental current, respectively, which are very low levels. The phase-shifting design of the 24-pulse multiwinding input transformer enables harmonic cancellation [13] and, ultimately, reduces the input harmonics imposed on the system that are attributable to the AFD. With this topology, both current and voltage harmonics are reduced to levels below those recommended by IEEE Standard 519-1992 [14]. Total harmonic distortion limits, as defined by this standard, are important, ensuring that the addition of a large nonlinear load, such as the 10 new AFDs required for this project, do not have adverse effects on other components included in the electrical system.

Other converter topologies include active front end (AFE) converters that also deliver high performance in terms of harmonic distortion. AFE converters include actively switched power electronics in the ac-to-dc section [15]. The passive switching design using a 24-pulse input transformer was the preferred approach specified by the project team. High-frequency switching at 2,400 V on the mill power system using an AFE drive was considered an additional potential risk, so this alternative technology was dismissed. Both the AFE and the 24-pulse designs mitigate line-side harmonics, and, for this mill system, both would be in compliance with recommended practices as outlined in IEEE Standard 519-1992.

**Motor Torque Performance Requirements**

One consideration regarding the AFD selection was the need to control the current to the motor stator windings to develop high-torque performance at the motor shaft. As discussed previously, the plug screw feeders applied in the chip pretreatment system were used to remove excess moisture from the chips in two processes: the first to dewater the chips before entering the impregnator vessel chemical bath and the second to remove excess liquid chemicals prior to entering primary refining. The project team was concerned that, after the process was stopped, restarting the plug screw feeder while loaded with compressed chips would be a challenge. Because of this, project specifications required that the 1,200-hp AFDs would have the capability to control current to the stator winding that would, in turn, deliver 100% load torque over the entire speed range, 150% of full-load torque for 30 s every 20 min, and 200% full-rated torque at locked rotor (load breakaway torque).

Most AFDs applied in industry today include sophisticated regulators with torque algorithms designed to
Figure 8. A schematic of the 2,300-V AFDs that were selected for the project. POS: positive; NEG: negative; NEUT: neutral; GND: ground.
optimize motor shaft torque. The traditional relationship between electrical energy and torque delivered to the motor shaft (horsepower = speed × torque) is augmented by real-time control of motor terminal voltage and current, which is modulated to maximize torque performance. The stator current for an induction motor is the vector sum of both the flux-producing magnetizing current and the torque producing (in-phase) current. The induction motor magnetizing current lags the stator voltage by 90° because the field winding is nearly pure inductance. The component of current that produces torque is in phase with the applied stator voltage. The AFD regulator isolates the magnitudes of these two torque components and uses them as feedback signals to regulate flux and torque independently. A closed loop controller uses both signals to produce balanced three-phase rotating command voltage vectors sent to the inverter modulator, which produces pulsedwidth modulation signals that drive the semiconductor switches of the inverter bridge. The inverter produces variable frequency, variable amplitude three-phase voltage fed to the induction motor stator. The selected AFDs for the project included high-performance vector controllers and were capable of delivering the specified high-torque performance, including more than 200% breakaway torque from zero speed.

**Fault Current and Arcing Current Protection**

An important functionality of the selected drive was the input protection. As shown in Figure 5 and discussed previously, the incoming section of the selected AFDs includes a line-side isolation switch followed by three current-limiting fuses and an input vacuum contactor. When the input disconnect is closed, power is applied to the soft-mag assembly, which partially charges the dc link capacitors. When the AFD receives 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 triggered to control the output waveform to the motor, which is a variable frequency and voltage output. The ratio of voltage to current is fixed based on the AFD voltage and frequency rating, in this case 2,300 V/60 Hz or 38.33 V/Hz.

Figure 8 shows that individual protective fuses supply 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. A single device failure in a diode front-end VFD 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 can result in higher arcing currents, creating a potentially dangerous condition for people working on or near this class of equipment while it is energized [16]. With the selected AFD design, which incorporated high-speed semiconductor fuses for each of the 24 converter diodes, plus additional current-limiting fuses at the AFD input, the possibility of an arc-back failure is effectively eliminated.

As shown in Figure 8, the AFDs incorporate a three-level neutral point clamped inverter topology that reduces the number of power-switching devices in the inverter, improving reliability via lower component counts. The inverter power-pole section, including the IGBT semiconductors and the respective gate drive printed circuit boards, are encased in a transparent silicone gel. This protects critical power electronic components from the elements and also enables the fast visual identification of a failed power device. Heat is extracted from this subassembly via a heat-pipe system [17] that moves it from the power semiconductors to the top-mounted subassembly fan units. Figure 9 shows two of the 1,200-hp AFDs installed for the TMP 2 project.

The project specifications required that factory-trained field service engineers be available during the start-up and commissioning of all new AFDs for both the TMP 1 and TMP 2 projects. Operator training and on-site spare parts were also included in the project’s scope since reliable operation of these AFDs was critically important to the newly installed process.

**Project Metrics**

Chip pretreatment and interstage screening for TMP 1 were commissioned in June 2011, with full operating production commencing in August 2011. Measurement and verification for TMP 1 occurred from August 2011 through January 2012. TMP 2 chip pretreatment and interstage screening were complete in November 2012, followed by measurement and verification of this project phase's elec-

Figure 9. The drives that were installed for plug screw feed pump loads.
trical energy savings, which were completed at the end of 2013. The total verified electrical savings for TMP 1 and TMP 2 exceeded 120 GWh of grid-level power per year, enough to serve the needs of roughly 8,000 households. In addition, 128,000 h of on-site work, primarily by contractors, was completed safely. Each project component started up on time and within budget. Overall, the project, which spanned more than 12 years from initial concept to successful completion, was deemed a tremendous success.

Conclusions

Competitive manufacturing in the current, challenging business environment requires innovation at every level of the organization. The high-energy intensity of TMP, coupled with a declining global market, has forced most legacy integrated TMP newsprint mills to drastically reduce capacity or simply go out of business. The TMP mill in this case study continues to operate profitably today due, in part, to this successfully planned and executed chip pretreatment and interstage screening project.

The focus on both energy and nonenergy improvements that could be implemented as a part of the project was an important element of the initiative's overall success [18]. The chip pretreatment upgrade allowed the mill to reduce the use of chemicals and lower input costs, while also adding the capability to process new varieties of wood chips and blends of recycled paper from an on-site drinking mill. The flexibility to deliver a variety of end-market paper grades has given the mill an opportunity to change its production mix based on market demands and improve profitability.

The selected electric power distribution and control systems installed to support this project were key elements to assure workplace safety and process reliability. An experienced team of engineers from the facility and the parent company’s engineering group worked together with product design and field service engineers from suppliers to specify and install systems that would perform best for the long term.

The project team worked to successfully leverage synergies between the mill site and corporate engineering, the serving utilities, key equipment suppliers, and contractors. The result: a viable and thriving business positioned to profitably serve new future markets.

Author Information

David B. Durocher (DavidBDurocher@eaton.com) is with Eaton, Wilsonville, Oregon. Mark Higginson is with North Pacific Paper, Longview, Washington. Durocher and Higginson are Senior Members of the IEEE. This article first appeared as “Successful Technology Upgrade Reduces Thermo-Mechanical Pulp Mill Energy Footprint” at the 2017 Annual IEEE Pulp, Paper, and Forest Industries Technical Conference. This article was reviewed by the IAS Pulp and Paper Industry Committee. It was approved for publication by Lanny Floyd, former editor-in-chief of IEEE Industry Applications Magazine.

References