UPGRADING POWER DISTRIBUTION EQUIPMENT – MAKING THE RIGHT CHOICES FOR RELIABLE PAPER MILL OPERATIONS

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***Abstract* – Most paper mills in North America were built in an era when main 15KV power distribution switchgear was only available with air-break power circuit breakers and relatively low MVA interrupting ratings. As mill capacity grows, facilities engineers are often faced with either upgrading or replacing existing main switchgear, to support required increases in interrupting ratings. This paper includes a study of two different mill sites with recent experiences in upgrading power distribution equipment by replacing vintage air-break circuit breakers with new vacuum circuit breakers in existing switchgear. The long-term potential benefits of both upgrade and replacement will be reviewed, including application considerations. At the end of the paper is an analysis of the total installed cost and impact on mill profitability by upgrading existing switchgear, versus replacement with new equipment.**

I. INTRODUCTION

The existing North American inventory of paper mills is older and less efficient than their counterparts in emerging markets such as Asia and South America. Over the past several years, North American paper companies have kept pace by adding new capacity using current technologies to compete in world markets. As capacity improvements in North American paper mills are on the increase, so too is the need to increase interrupting ratings of main power distribution switchgear. Capacity expansion will likely result in a need to review interrupting ratings for existing equipment in order to assure that the electrical distribution system is able to support the additional source megavolt amperes (MVA).

To add to the opportunity for overdutied power distribution, today's energy-deregulated environment increases the likelihood of additional generating capacity being installed at a paper mill site. There are a number of planned and ongoing projects in North America where gas and combined-cycle power plants are being funded by utilities and independent power producers. Steam and power utilization make a paper mill an excellent candidate for a new generation site. Additional on-site generation often requires mill power distribution equipment replacement or upgrade to support the increased MVA capacity.

Unfortunately, investment to replace electrical power distribution equipment often gets less attention than other projects that can be clearly justified based on production improvements. Mill electrical engineers are often faced with applying "band-aid" solutions such as current-limiting reactors to deal with MVA capacity increases. In today's cost containment environment, it is difficult to justify capital expenditures for power distribution switchgear unless a clear case for increased production, safety, or cost avoidance can be made. Often, power distribution equipment must fail or be the cause of significant lost production before an upgrade or replacement is considered.

One viable alternative to replacement of overdutied power distribution switchgear is the upgrade of existing equipment. Two North American based paper mills have recently implemented such upgrades: International Paper's (IP's) Androscoggin, Maine mill and Buckeye Technologies' Perry, Florida mill.

II. INTERNATIONAL PAPER'S ANDROSCOGGIN MILL SWITCHGEAR UPGRADE

International Paper's Androscoggin mill located in Jay, Maine, was originally built in 1965. Over the years, mill capacity has grown to include five paper machines, two chemical pulp mills and a groundwood mill. Total electrical consumption is 120 megawatts (MW), with 80MWs generated by three mill owned and operated steam turbine-generators, and 20MWs generated by three IP operated hydro power plants. The mill purchases the balance of 20MW from the local utility. In 1998, a third-party independent power producer agreed with IP Androscoggin to construct, own and operate a 150MW gas-fired power plant at the mill site. The project was inspired by a new gas pipeline originating in Canada running through the state of Maine, coupled with state legislation approving utility deregulation. The new plant was constructed in 1999, and three new 50MW gas-fired turbines have since been commissioned. Both companies signed long term power and steam contracts. IP benefited from a fixed steam purchase agreement as well as a contract to purchase electricity from the independent power company. The power producer benefited by the use of the paper mill as a "heat-sink" to consume excess low-pressure steam from the gas turbines that is used in the paper making process. IP was also able to shut down two existing power boilers that were marginal performers. These boilers burned #6 fuel oil, transported by truck to the mill site. The state of Maine implemented utility deregulation starting in March 2000, so both the mill and the independent power producer are now able to sell excess electrical power on the open market via the utility grid.

With the help of a recently conducted power systems and load-flow study, the Androscoggin mill engineering team was able to easily determine that the new gas-fired co-generation plant would render the 15KV “Bus A” switchgear overdutied. The study actually proved essential in helping the mill negotiate with the third-party independent power producer to justify a new load capacity upgrade of the utility tie from 28MVA to 50MVA. The cost of this upgrade was borne by the third-party independent power company as a part of the work scope of the project. The result was a more reliable utility tie feeding the mill.

The “Bus A” switchgear line-up was installed when the mill was originally built in 1965. The switchgear was Westinghouse air-magnetic type DHP, with an interrupting rating of 500 MVA. The mill upgraded this equipment rating in 1967 to 750MVA. A current-limiting reactor upstream of the “A Bus” switchgear was included in the original installation. This reactor provided system fault protection, given the utility tie MVA capacity. It also acted as an electrical “cushion” in protecting the mill steam turbine-generators from line voltage transients. The new 150MW gas-fired power plant drove source MVA requirements up again, resulting in a need to increase the “Bus A” switchgear interrupting rating from 750MVA to 1000MVA. IP engineers assembled a project team to carefully review the alternatives of replacement versus upgrade of the “Bus A” switchgear to support the new power plant project. After exhaustive analysis, the project team selected a switchgear upgrade with replacement breakers as the best approach. A simplified one-line diagram of the mill power-distribution system with the new gas-fired co-generation plant and upgraded “Bus A” switchgear installed is shown in Fig. 1 below.

A. IP Androscoggin Project Upgrade Alternatives

Because the existing switchgear and circuit breakers were overdutied with the additional generation, both had to be upgraded to the new 1000MVA rating to support the added capacity of the 150MW generators. IP’s project team selected the local field service engineering organization of the switchgear equipment manufacturer to work with them on a turnkey basis for the “Bus A” project. IP used past mill experience and familiarity with equipment design and fabrication as the basis for supplier selection. Together, the mill and service engineering group worked to review possible alternatives for the project work.

1) Switchgear Replacement – New Breakers: Initially, the most appealing solution for implementing the upgrade was to replace the existing air-magnetic switchgear with new vacuum switchgear. Since the “Bus A” switchgear was over 30 years old, it had served a useful life and new equipment would carry a new factory warranty and certainly be the most reliable solution. After the project team reviewed this option, there were a few significant drawbacks to replacement. First was the initial cost of purchasing new equipment. Although the mill had kept excellent records of mill downtime attributable to the reliability of the “Bus A” switchgear, even the best case scenario of improved production due to “perfect” switchgear reliability did not come close to the mill’s established goal for return on investment, required to financially justify the added expense.

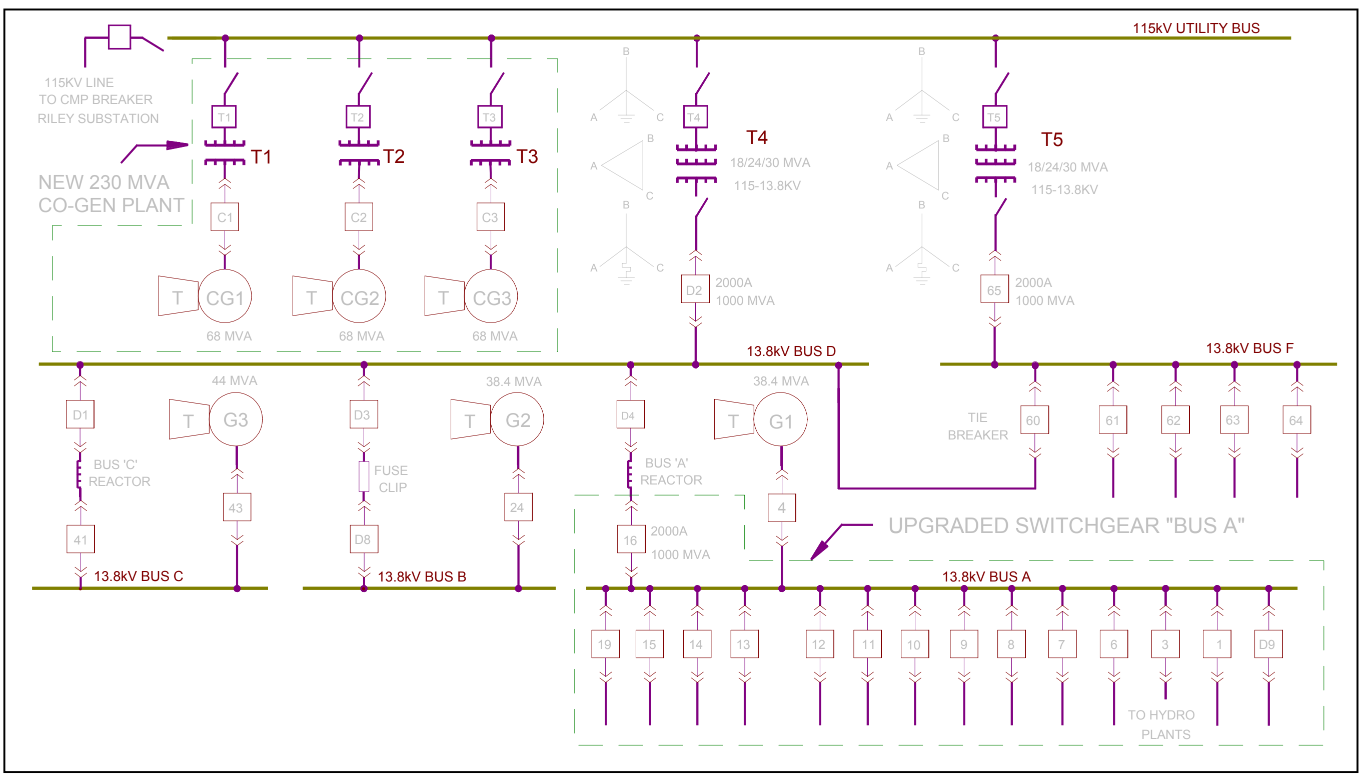

Fig. 1: International Paper Androscoggin Mill One-Line Diagram after new Gas-fired Co-generation plant and “Bus A” Upgrade.

Secondly, installing new switchgear would increase the required mill downtime during a changeover versus retrofit. A 36 hour mill outage was determined to be necessary, based on previous experience in other IP mills and other similar switchgear replacement projects [1]. Because of the cost and downtime disadvantages, other options were explored.

2) Switchgear Upgrade – Rebuilt Breakers: The equipment manufacturer's service engineering group researched the original shop order of the existing switchgear. Through the use of a bus-upgrade computer simulation model, it was determined that additional structural supports could be provided by the factory and field installed to increase the switchgear bus bracing to the required 1000MVA rating. This opened the door to the possibility of upgrading the existing switchgear lineup.

Various options were considered to upgrade the existing circuit breakers. The existing equipment was supplied with 500MVA rated air-magnetic breakers and later field upgraded to 750MVA. The project team investigated the option of rebuilding the existing air-magnetic breakers. Although the first cost of this approach was attractive, the mill wanted improved performance and reliability. Air-magnetic technology inherently required more maintenance, including inspection and cleaning after every breaker interruption. This option was ultimately rejected on the grounds of lower reliability, increased maintenance and increased mill downtime requirements during the upgrade.

3) Switchgear Upgrade – Retrofit Breakers: Vacuum retrofit circuit breakers were also considered as an alternative. Several equipment manufacturers had commercially available technology to remove the existing air-magnetic elements (including the arc chute) and replace them with a new vacuum interrupter package, along with new bushings, interlocks and mechanism. This technique for switchgear upgrades has successfully been implemented in other paper mills and documented in previous technical papers [2]. Although there were early problems with well-intentioned vendors entering the vacuum retrofit business with little or no experience, there is now an IEEE Standard that clearly defines retrofit requirements [3]. For this project, vacuum retrofit would require that two breakers at a time be removed and transported over 150 miles away to a facility in Boston, Massachusetts (there were two available spares at the mill that could be used while two were being retrofitted). Turn-around time for each set of retrofit breakers was 4-6 weeks. Upgrading the entire line-up would have taken months. In addition, this approach would have used some existing parts from the original breakers. Although the IEEE Standard defines minimum requirements for reliable operation, some parts such as the breaker frame, primary finger clusters and breaker operating mechanism are often re-used in a retrofit breaker. Numerous parts would have required hand fitting, adding to the possibility of human error. Inconsistent test procedures for retrofit breakers could have also led to compromised reliability. For these reasons, the vacuum retrofit option was dismissed.

4) Switchgear Upgrade – Replacement Breakers: The mill ultimately selected replacement breakers for the "Bus A" upgrade. The replacement breaker approach essentially involved removal and disposal of the old air-magnetic breakers, replacing them with totally new vacuum breakers. This product was newly manufactured by the original equipment supplier, using the current design vacuum interrupter and operating mechanism. The new breaker was mechanically and electrically interchangeable with the existing air-magnetic breakers. Replacement breakers were subject to the same ANSI test procedures as a breaker made for installation in new vacuum switchgear. Design Certification Testing requirements included:

- 95KV BIL Test for 8.25-15KV Rating
- Continuous Current with 65^0C rise over a 40^0C ambient
- Momentary Close and Latch per C27.20.2
- Mechanism Operated Cell Switch test to 10,000 operations
- I^2T 3 Second Withstand Energy Test
- Mechanical Endurance Tests
- Production Tests to ANSI C37.09.05

Although the replacement breaker option involved a slightly higher cost than the vacuum retrofit approach, the replacement breaker option was selected. IP's mill engineering team liked the increased reliability of a new vacuum breaker and the rigorous testing requirements defined by the ANSI Standards [4]. Table 1 below shows a summary of the key decision criteria used by the mill to ultimately select the replacement breaker approach over other alternatives.

TABLE 1

DECISION CRITERIA FOR SWITCHGEAR UPGRADE

Alternative	Initial Cost	Cost to Maintain	Reliability/ Maintainability	Required Downtime
New Switchgear	High	Low	Maximized	High
Rebuild Existing Breakers	Low	High	Minimal	Very High
Vacuum Retrofit Breakers	Moderate	Low	Moderate	Very High
New Vacuum Breakers	Moderate	Low	Maximized	Lowest

B. Upgrade of "Bus A" Switchgear at IP Androscoggin

The total work scope of the project required a fairly large number of personnel in tight quarters. A decision had to be made to set the length of the outage. There was a trade-off in determining the required outage time in terms of lost production versus labor costs and risks during the project. IP assigned the supplier's service group lead responsibility to coordinate total engineering support and contract labor. This allowed the mill's staff to focus on other areas of the mill that needed to be attended to during the scheduled outage. The manufacturer's service team worked with the mill to set the planned outage time for 14 hours. This was an aggressive outage plan for the project. But, with the “Bus A” switchgear feeding both paper machines 1 & 2, production costs were a significant factor. An additional 10 hours was established as a “contingency” plan since the condition of the bus and cable feeders was not known at the time the outage was scheduled.

1) Before The Mill Shutdown: A comprehensive upgrade plan was written by the project team and approved by mill engineering management. All work that could be performed in advance of the shutdown was scheduled and accomplished. This included receiving the 19 new vacuum circuit breakers and storing them in a designated staging area as shown in Fig. 2. Fortunately, the “Bus A” switchgear was in a large equipment room that housed the 15kV distribution along with three steam turbine-generators. There was room for all of the new breakers close to the existing switchgear. The manufacturer’s service team completed a thorough checkout and test of each breaker in preparation for the scheduled shutdown. Tests included visual inspection for shipping damage, vacuum bottle contact wipe, travel and vacuum seal check, latch and control switch check, adjustments, lubrication, electrical operation, auxiliary contact operation and insulation integrity.

Fig. 2: Replacement breakers are positioned in staging area before scheduled upgrade.

Bus bracing components shipped from the manufacturer were inspected and mechanically checked. These were to be installed from the front of the cell during the shutdown, after removal of the breaker element and the compartment cover plate. Each breaker cubicle was outfitted with its own unique punch-list of activities required in the cell. This list included testing procedures after the new breaker was in place. The plan was to have electricians work independently within an assigned breaker cubicle to remove the existing breaker, upgrade the cubicle bus bracing, install the new breaker and then complete all control test procedures before the equipment was re-energized. The protective relays and associated control wiring in each cubicle were to remain intact after the upgrade. From past experience, the mill staff felt that disturbing existing control and power wiring would likely compromise the integrity of the switchgear line-up.

2) During The Mill Shutdown: During the scheduled outage, a total of two engineers and 10 technicians were on site to perform the work. The first 4-5 hours of the scheduled 14-hour outage were used for implementation of the standard IP lock-out/tag-out procedures. This work was accomplished by mill electricians and was completed on schedule. The switchgear upgrade team was then deployed to upgrade the existing “Bus A” switchgear as shown in Fig. 3.

Fig. 3: During the scheduled 14 hour shutdown, a total of 2 engineers and 10 technicians from the manufacturer’s engineering services organization were deployed for the upgrade.

The work performed was somewhat complicated by the need to remove some glastic boxes from over the original air interrupter arc chutes. These were installed during the 1967 upgrade of the “Bus A” switchgear in order to increase the interrupting rating of the equipment to 750MVA. With the new vacuum breakers, the added phase barriers were not needed.

The old breaker elements were removed and set off to the side. Each compartment cover plate was then removed, in order to gain access to the main horizontal bus. Additional bus bracing supports were then installed in each cubicle. Bus and cable terminations were carefully inspected from both the front and rear cubicle compartments. Care was taken not to disturb the power cables while thoroughly checking the terminations and bus integrity. A few sections of the main bus showed signs of tracking. A decision was made to dedicate another 10 hours during the shutdown to replace selected sections of the main bus that showed signs of potential problems. The team was prepared with extra bus and insulation material to accomplish this task.

After the new bracing and main bus were installed, the technicians closed each compartment by replacing the cover plate as shown in Fig. 4. No cell modifications were required, since the replacement breakers were matched to shop order numbers from the original switchgear. This assured that all primary stabs and secondary connections were identical to the original equipment installed in 1965. Cubicle “code plates” were installed to assure that a 1200 ampere breaker could not be racked into a 2000 ampere breaker cell. With the main bus still de-energized, each breaker was again tested with the original relays, and all relay setting were checked and verified.

Fig. 4: A service engineer installs the main bus compartment cover plate after new bus bracing to increase interrupting rating to 1000MVA has been installed (arrow shows new bracing added in the field).

A picture of an upgraded cubicle is shown in Fig. 5. Interestingly enough, part of the upgrade agreement with the service contractor included providing a credit for return of the old air-magnetic breakers. The mill didn't want the old breakers, and they had some salvage value in the used parts market.

Fig. 5: Photo of the completed installation of a new replacement breaker in the upgraded "Bus A" switchgear. Original control and power wiring as well as protective relays were inspected, tested and re-commissioned.

II. BUCKEYE TECHNOLOGIES PERRY MILL SWITCHGEAR UPGRADE

The Buckeye Technologies mill in Perry, Florida, was built in 1953. The mill has two pulp machines, producing Kraft Market Pulp and Fluff Market Pulp used in various specialty applications. Total mill electrical load is nearly 50 MW's. Four on-site non-condensing steam turbine generators produce a total of 42 MW's, with the balance of electrical power being purchased from the local utility. The 15KV primary switchgear in the mill was Westinghouse air-magnetic Type DH, an obsolete vintage. The original switchgear supplied was rated at 500MVA. In 1980, the switchgear was upgraded to 750MVA in order to meet new generating capacity installed at the mill. This upgrade was performed by the switchgear manufacturer's service organization and involved modification of both the air-magnetic breaker elements and the switchgear bus bracing. Similar to the scenario presented in the previous case, this process involved upgrading two air-magnetic circuit breakers at a time. Breakers were shipped to an off-site service facility for upgrade, and then returned to the mill.

Over the course of several years of operation, the mill engineering staff carefully tracked the operation of the 18 breakers in the main switchgear line-up. Preventive maintenance records were kept for each breaker, recording circuit interruptions, routine inspections and maintenance. The mill requirement to inspect and clean arc chutes on air-magnetic breakers after every fault interruption occasionally resulted in costly downtime. This, coupled with other routine maintenance as recommended by the manufacturer, resulted in a one-year maintenance rotation for the breakers in Buckeye's main switchgear. Because the mill maintenance rotation for other major equipment (such as the turbine generators) was on a three-year cycle, the main switchgear became a focal point in determining ways to improve mill uptime. Since feeder breakers were dedicated to common mill processes, a plan was put into place to retrofit two of the 18 breakers feeding the powerhouse to vacuum technology.

In 1987, during a cold outage, two of the existing type DH air-magnetic breakers were shipped to a nearby facility in Georgia for a vacuum retrofit upgrade. The breakers were torn down to the frame and then re-built using a new vacuum interrupter and mechanism. This upgrade was considered a success and allowed the powerhouse area of the mill to switch from a once-a-year maintenance cycle to a three-year maintenance cycle.

Following this same concept, mill engineering identified five additional feeder breakers in the main switchgear that if replaced, could save the mill the cost of annual cold outages and improve overall production. In 1998, the mill ordered five new vacuum replacement breakers and implemented a plan to replace the existing air-magnetic breakers during a scheduled electrical outage. Although the original air-magnetic breakers were obsolete, the replacement vacuum breakers were designed by the manufacturer from the original drawings and thus were mechanically and electrically interchangeable with the originals.

A. Buckeye Switchgear Upgrade Alternatives

Unlike the IP Androscoggin upgrade, the Buckeye Technologies main switchgear was never considered a candidate for replacement. Improving overall reliability of the electrical distribution system drove the upgrade decision.

In 1987, when the first two breakers were retrofitted with vacuum interrupters, there were no standard designs available for replacement breakers to fit in the type DH cell. The 1998 upgrade decision was made in favor of vacuum replacement breakers, since standard designs to fit in the existing type DH cell were commercially available. This decision was made primarily due to cost, with vacuum replacement versus vacuum retrofit being nearly the same for the five breakers.

Logistics of the retrofit option would have been more complex, since the mill did not have five spare breakers to install in the existing cubicles while the air magnetic elements were being upgraded. There were some suppliers that could have provided “loaner” breakers during the retrofit, but finding an exact match for this many obsolete breakers proved to be difficult. Also, one benefit of the vacuum replacement breaker option was that all of the existing air magnetic breakers were retained by Buckeye and used as active spares. Since this project did not involve an increase in the switchgear and breaker MVA rating, the old breakers could easily be used as backup. With this additional resource, downtime as a result of a future breaker interruption could be held to a minimum. To keep the mill running, a spare breaker could easily be racked into the cell while the breaker that interrupted was cleaned and inspected.

B. Upgrade of Main Switchgear at Buckeye Mill

After the five new replacement breakers were shipped to the mill, Buckeye Technologies maintenance personnel coordinated all inspections before the equipment was put in to service. A spare cubicle in the main switchgear was available and used to physically rack all five new vacuum replacement breakers in and out to assure mechanical interchangeability. Buckeye identified minor cell modifications required, involving removal of a ¾” channel on either side of the cubicle. This modification was necessary due to product design revisions made by the manufacturer back in the late 1950’s. One of Buckeye’s design requirements for the upgrade was that every breaker must be interchangeable into every cell. So, all cells were modified to accommodate the new vacuum breakers. Electrical tests were performed with careful attention to the secondary connections and relay settings. All of the original control and power wires as well as the protective relaying were left intact.

Mill procedures dictated that replacement of power cables came as a result of capacity changes only. The mill tracked preventive maintenance history and circuit interruptions of all 15KV feeder cable. Mill engineering felt comfortable that feeder cable integrity would not be an issue, even though some cables were over 40 years old. Total downtime as a result of the 5-breaker upgrade was less than four hours. The Buckeye engineering and maintenance team performed all of the work during a routine scheduled outage.

As a result of the upgrade, the mill was able to change maintenance rotation for the 5 new vacuum replacement breakers from one year to three years. Since the new breakers were tied to a common mill process, this upgrade resulted in higher mill uptime and overall improved reliability.

III. AIR TO VACUUM APPLICATION CONSIDERATIONS

Virtually every medium voltage switchgear lineup with air-magnetic circuit breakers became obsolete in the 1960’s and 1970’s after vacuum technology came of age. Fortunately, vacuum replacement breaker designs are commercially available from several reputable manufacturers. As an example, obsolete air-magnetic switchgear breakers originally manufactured by Westinghouse, General Electric, Allis Chalmers, ITE/ABB, Federal Pacific and McGraw Edison all have current design vacuum replacement counterparts. Table 2 provides a reference showing most replacement breakers available in the industry today.

TABLE 2

INDUSTRY AVAILABLE VACUUM REPLACEMENT BREAKER DESIGNS FOR OBSOLETE AIR-MAGNETIC BREAKERS (BY MANUFACTURER)

KV Class	Nominal MVA Class	Continuous Current Rating	Original Manufacturer	Manufacturer Obsolete Breaker Series
4.76	250	1200 2000	Westinghouse	DH/DHP
4.76	350	1200 2000 3000	Westinghouse	DH/DHP
8.25-15	500-750	1200 2000	Westinghouse	DH/DHP
15	1000	1200 2000 3000	Westinghouse	DH/DHP
4.76	250	1200 2000	General Electric	AM4.16/ AM5
4.76	350	1200 2000 3000	General Electric	AM4.16
8.25-15	500-1000	1200 2000	General Electric	AM7.2 AM13.8 AM15
4.76-15	250-750	1200 2000	Allis-Chalmers	AM/MA FB/FC
4.76-15	250-750	1200 2000	ITE/ABB	HV/HK
4.76-15	250-750	1200 2000	Federal Pacific	DST/DST-2
4.76-15	250-750	1200 2000	McGraw Edison	WSA/PSD

Regardless of the replacement breaker manufacturer, the mill engineer should consider a few application issues when applying a new vacuum breaker in a cell of an existing air-magnetic breaker.

A. Surge Protection Requirements for Vacuum Interrupter Technology

Should the mill install surge protection to protect downstream equipment from switching transients caused by vacuum replacement breakers? Earlier industry papers have identified the need to add surge arresters to all vacuum breakers as a standard requirement [1]. Today, surge arresters are generally <u>not</u> a requirement for vacuum circuit breakers. In the case of the two switchgear upgrades that are the subject of this paper, neither was installed with surge arresters.

It is true that early application of vacuum interrupter (VI) technology back in the 1960’s caused some concerns over switching transients. Because early design VI’s exhibited problems with chop current and multiple re-ignitions (or re-strike), surge protection was common practice.

1) Chop Current for VI's: Chop current is caused by an instability during arc interruption just before the natural current zero in an AC circuit. A sudden collapse of current flow just before current zero causes a corresponding voltage transient at the VI load circuit. Chop current is present during interruption by all types of contacts (oil, SF6, air and vacuum). Starting in 1970, most VI manufacturers switched their contact material from Cu-Bi to Cu-Cr for circuit breaker applications. The selection of contact material has reduced average chop current to about 3 amperes, with a maximum of about 5 amperes [5]. These values would result in a corresponding voltage rise in a motor circuit of only 3 P.U., a value well below the IEEE design impulse level of 4.5 P.U. Although most vacuum breakers service transformers, not motor loads, motors are considered the load most potentially vulnerable to voltage surges.

2) Re-strike or Multiple Re-ignition for VI's: Either re-strikes or Multiple re-ignitions can occur when the VI's transient recovery voltage (TRV) is above the device's transient breakdown voltage, causing re-ignition of the arc [5]. Once the VI has interrupted the current, a TRV appears across the contact gap. This TRV is a function of the reactive components of a given circuit. If the contact gap is not fully open and the TRV exceeds the VI's breakdown strength, the arc can be reestablished. The breakdown voltage rating of the VI depends almost exclusively on the contact gap. If the VI contacts part with sufficient speed, the chance for multiple restrike is nearly eliminated. Again, most modern design VI's operate in a range where this is not a factor, and surge protection provides no benefit. The user should however be aware of these issues and consult with the VI supplier regarding the potential requirement for surge suppression.

B. Interface With Mechanism Operated Contact Switches

One of the important application considerations in retrofitting existing air magnetic switchgear with retrofit or replacement vacuum circuit breakers is safe and reliable operation of the Mechanism Operated Contact (MOC) switch. The MOC switch is a set of auxiliary contacts mounted external to the breaker in the cell, driven by the breaker mechanism. These switches typically are used in the control scheme to indicate breaker position and can include up to three separate switches driven by a common operator (see Fig. 6). In a vacuum retrofit or replacement application, often the existing MOC switches will remain in the cell and the new breaker mechanism will control the MOC switch. The mismatch in breaker operating performance between air magnetic and vacuum mechanisms causes a potential problem that must be addressed.

Air magnetic breakers have a very long contact stroke with a heavy contact mass. The result is a slow response time, often up to 100 milliseconds (ms) to close and 55ms to open. Conversely, the vacuum breaker has a much smaller contact stroke with lighter moving contact mass. The result is a much faster response time, often less than 25ms to close and 15ms to open. The breaker mechanism linkage to the MOC operator arm is via a pantograph, which allows the breaker to operate the MOC in both the connected and test positions and to be released from the MOC linkage when the

Fig. 6: Three Mechanism Operated Contacts (MOCs) mounted in a cell with mechanical (Drive Rod) linkage to the breaker operating mechanism.

breaker is in the disconnect position or removed. A diagram showing the operation of the MOC is shown in Fig. 7.

When the vacuum breaker mechanism attempts to operate the mechanical linkage of the MOC from the original cell, it does this at 4 times the velocity and 16 times the kinetic energy of the air-magnetic breaker mechanism. The increased mechanism travel speed results in pantograph over-travel and rebound which can cause significant problems. In most conditions, this will result in the MOC contacts bouncing, giving false indication of breaker position during open or close

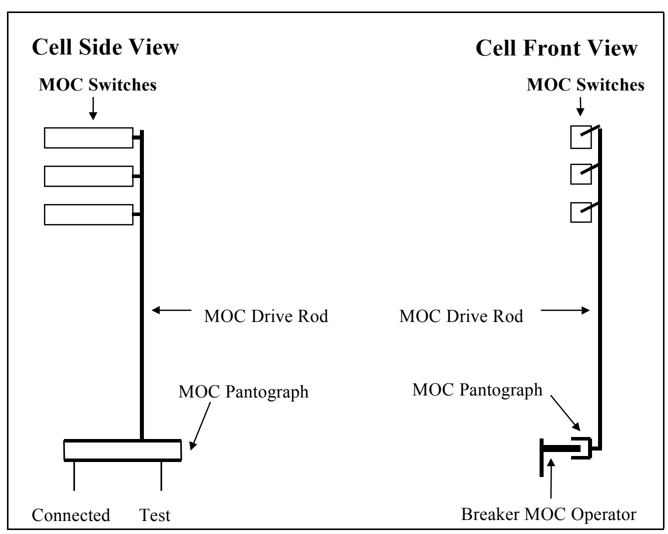

Fig. 7: Functional Operation of Mechanism Operated Cell Switch

transitions. In some conditions, the MOC can completely stall the breaker, resulting in a serious safety concern.

To remedy this potential problem, a MOC interface that effectively decouples the breaker and MOC switch operation can be used. This "sure-close" operator is a stored energy device that allows the MOC to open and close independent of the breaker mechanism. Fig. 8 shows the MOC switch close transition for the original air magnetic breaker, the vacuum breaker without the decoupled interface device and the vacuum breaker with the stored energy "sure- close" device. The end result is reliable, safe operation with little or no MOC switch over-travel and no chance for a breaker stall condition. Any vacuum retrofit or replacement breaker applied in an existing air-magnetic cell with a MOC switch should include a provision to resolve this inherent mechanism response time issue.

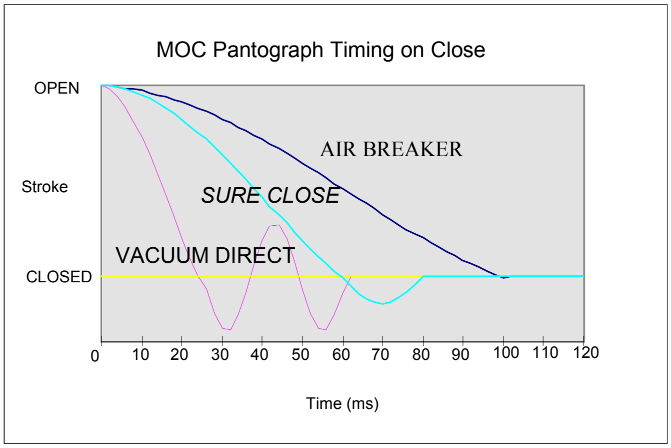

Fig. 8: Motor Operated Cell Switch Pantograph Timing for Original Air Breaker, New Vacuum Breaker and Vacuum Breaker with Sure-Close Operator.

IV. DISCUSSION OF REPLACEMENT VERSUS UPGRADE

Both of the mill switchgear upgrade experiences discussed in this paper involved the use of retrofit or replacement vacuum breakers in existing air-magnetic switchgear cells. Replacement of existing air-magnetic switchgear with new vacuum switchgear is also a viable option to be considered. This section of the paper addresses product reliability issues that should be reviewed when considering the option of switchgear replacement versus upgrade. A review of the financial implications on mill profitability is also addressed.

A. Power Distribution System Reliability

The IEEE Standard concerning the reliability of electrical distribution systems [6] publishes failure information for a majority of the electrical distribution equipment in use today. The summary of *hours of downtime per failure* published in this standard shows that the median plant average for downtime of a failed circuit breaker rated above 600 volts is 168 hours. This failure information is separate from switchgear associated failures. The survey information from the standard indicates that 74% of breaker failures require around the clock repair. In today's typical paper mill, downtime costs are in the range of $7,000-$80,000 per hour, depending on the specific process involved. Using the IEEE standard, a switchgear breaker failure can cost a paper mill over $1.0 million in lost revenue. Since paper is a process industry, most mills maintain active spare breakers as a means to minimize the impact of a breaker failure on production. It's interesting to note that the IEEE standard identifies the two main causes of breaker failure as: 1) Opening when it should not have opened (about half of these incidents are presumed to be caused by relay operation) and 2) Failing while in service. These modes of failure account for nearly 75% of all breaker failures. For these reasons, reliable breaker operation is critical to any successful and profitable mill.

1) Circuit Breaker Reliability: It has been proven that vacuum circuit breakers are superior in reliability and safety to air-magnetic designs. The vacuum arc is contained within a sealed bottle assembly, while the air-magnetic breaker involves combustive gasses that are emitted in open air during arc interruption.

Comparing the reliability of vacuum retrofit breakers to vacuum replacement breakers yields a slight advantage in favor of vacuum replacement. Vacuum retrofits typically use some of the old air-magnetic parts, and are tested to a less stringent standard than replacements. Thus, the projected reliability of vacuum retrofit breakers is inherently less than that of their vacuum replacement counterparts.

Breaker reliability for new vacuum circuit breakers versus replacement vacuum breakers is identical. Since vacuum replacement breakers are assembled from all new parts and are subject to the same test standards as breakers used in current designs of vacuum switchgear, the reliability of the replacement breaker itself is equal to a new breaker. As a result, the discussion of overall power distribution system reliability for upgraded versus new switchgear should be tied to the integrity of the switchgear itself.

2) Bus and Structure Reliability: All switchgear assemblies consist primarily of steel and copper, taking the form of enclosure structure and bus. Certainly, new switchgear is more reliable than 20-30 year old existing switchgear. However, experience has shown that the condition of the existing equipment is a significant factor in reduced maintenance costs and downtime. A good preventive maintenance program in a mill can often assure that 40 year old switchgear looks and performs like 5 year old switchgear in terms of reliability. If the mill elects to pursue the switchgear upgrade option, a solid history of preventive maintenance for the existing switchgear is very important. Also, any switchgear upgrade should include ample time during the scheduled outage to inspect the bus system, replacing suspect bus and insulation. This approach was used effectively during the IP Androscoggin upgrade.

3) Power and Control Wiring Reliability: Replacing load cables is a major decision in considering upgrade versus replacement. In general, it is difficult or impossible to maintain power conductor integrity if it is disturbed during the upgrade. Since a new switchgear installation requires the disconnecting of old cables, careful consideration should be given to their reuse. Even the slightest movement of older cables can cause cracking and failure whereas if undisturbed, existing cables will function reliably for many years. Replacing switchgear can often result in the requirement to replace feeder cables. This adds to the expense and downtime in replacing old switchgear with new.

In the two upgrades discussed in this paper, both mills elected to retain the existing protective relays, metering and associated control wiring within the breaker cubicle. Mill engineers from both locations identified existing control wiring as being the possible "weakest link" in the upgraded switchgear. Just as for the power wiring, age will eventually render control wiring brittle, with increased risk of insulation failure. If the existing relays are used, care should be taken not to disturb the existing control wiring during the upgrade.

4) Protective Relay Reliability: The integrity of the existing protective relays and metering should be thoroughly reviewed and considered as a part of any switchgear upgrade project. If the relays are to be replaced, the mill should consider upgrading to multi-function electronic protective relays. Several manufacturers have these products available and can assist a mill in considering this alternative to update the relay protection. If this option is selected, an appropriate amount of additional time should be set aside during the outage to perform this work. New relays and wiring should be completed in sub-assemblies, perhaps mounted and wired on replacement doors, to minimize human error as well as the time required for an upgrade.

Any upgrade involving increasing the switchgear MVA interrupting capacity should also include careful analysis of switchgear relay coordination. Downstream equipment ratings need to be verified, to assure withstand capability is based on the increased fault duty. If downstream loads are low voltage unit substations with a primary fused switch, the switch and fuse ratings will need to be checked to verify sufficient capacity. A complete mill power system study is a good tool to assure that all equipment is rated to safely withstand and interrupt potential faults.

5) Reliability Based on Maintenance History: It is important to note that all switchgear is <u>not</u> created equal. In other words, a significant factor to consider before upgrading any equipment is its condition at the time of the upgrade. Routine maintenance is a must in order to have a functional assembly that will be a source of confidence into the future. If the existing equipment has not been adequately maintained, do not consider putting more money into it. If the existing switchgear has survived a hostile environment in the mill, the integrity of the components and assembly have likely been compromised. No amount of band-aids can fix a marginal lineup of switchgear. Likewise, it is important to consider the design of the air magnetic switchgear you have today. If the design was poorly constructed, or if the original mechanical design is marginal, it will be less likely to perform reliably in the future. Often, manufacturers or consultants can assist in helping a mill make these determinations.

B. Reliability Upgrade Opportunities

If the decision is made to upgrade existing equipment, there are a few opportunities for mill engineering to "supercharge" their existing switchgear to improve its reliability and performance.

One consideration would be adding new electronic metering with network communications to the switchgear. Since 15KV switchgear is typically at the mill point of service with the utility, it is desirable to have a revenue class, ANSI C.12 rated meter at the switchgear main breaker. The utility will recognize this instrument as revenue class, and it can be used for verification of the mills' monthly utility bill. Many of these meters also have sophisticated capabilities to accurately measure harmonics as well as capture and record high-speed events such as voltage surges, sags and swells. In tomorrow's world of utility deregulation, having this class of meter at the mill point of service could prove very valuable in understanding more about the mill's power quality as well as quantity. These meters can be networked together and will easily communicate over the mill-wide Local Area Network (LAN) for database trending.

Another technology that should be considered is the addition of partial discharge (PD) sensors in the switchgear. Partial discharge technology allows for on-line diagnostics of the switchgear bus and identifies potential problems in the bus insulation system before they occur [7]. This technology has been applied successfully for several years in medium-voltage (MV) motor on-line insulation testing, and was recently developed for use in MV switchgear. Partial discharge protected Metal-Clad switchgear is commercially available today as a new product. Although this option was not available during the two referenced projects, there is nothing to prevent PD application in existing equipment, installed as an upgrade.

Both revenue class electronic metering and PD sensor additions should be considered as a part of any switchgear equipment upgrade. The cost of both to install as a retrofit is very low as compared to the resulting benefit.

C. Impact on Mill Profitability

Capital Intensity are the two words that have won the hearts and minds of every top executive in the Pulp & Paper Industry. The industry has the distinction of consistently maintaining a higher cost of capital than any other industry [8]. In order for the Pulp & Paper Industry to effectively improve shareholder value and compete with investor returns comparable to other industries, it will need to better manage capital outlay for facility improvements. For this reason, a thorough review of the financial impact on mill profitability for switchgear replacement versus upgrade must be considered in addition to the technical and operational issues.

Although the IP Androscoggin "Bus A" project was installed based on an upgrade of 35 year old switchgear, the installation can serve as a good example in reviewing the financial impact of replace versus upgrade alternatives. Appendix A of this paper includes an itemized list of all material, man-hours and other associated costs of the "Bus A" upgrade at the IP Androscoggin Mill. The cost summary was based on actual mill expenses associated with the project. Appendix B of this paper includes an itemized list of all material, man-hours and other associated costs to replace the "Bus A" switchgear with new equipment. As discussed previously, this option was initially reviewed by the project team, but not selected. Thus, a reasonable cost *estimate* of material and labor hours has been made based on manufacturer's inputs using actual market level pricing for the new switchgear, as well as *estimated* costs for engineering and trade labor to complete the project.

Appendix C and Appendix D of this paper include a five year total Cost Benefit Analysis for the actual switchgear upgrade and a Cost Benefit Analysis estimate for switchgear replacement, respectively. This financial tool proved helpful in determining the payback for the project, including both the capital cost to the mill as well as revenue increases realized as a result of the addition.

Total mill downtime for the "Bus A" switchgear upgrade analysis was based on 14 hours. Although the total time to complete the project was 24 hours (including a 10 hour contingency used to replace some main bus sections), most of the final 10 hours was used during a scheduled cold outage for the entire mill, and thus this time was not necessary for successful project completion. Total mill downtime for the switchgear replacement analysis was estimated at 36 hours. This was based on mill engineering estimates along with actual data from previous upgrades where similar equipment was replaced [1]. Mill downtime cost per hour was estimated at $40,000. This was a reasonable downtime cost per hour for this application, considering that "Bus A" switchgear feeds two paper machines, one pulp mill, and additives for all five paper machines.

In both cases, there were two realized benefits resulting in additional revenue to the mill. First, increasing the switchgear rating to 1000MVA allowed for reduction of the "Bus A" current limiting reactor to just below 10% impedance due to improved voltage regulation. This was significant because when Generator G1 (see Fig. 1) went down for maintenance rotation every two years, the new switchgear could now support 100% of its load via the utility bus. Before the upgrade, one paper machine needed to be taken down during the generator maintenance outage, resulting in a 96 hour production loss. Second, there was a utility bill benefit of $20,000 in savings per year based on using the smaller "Bus A" current limiting reactor. There were other benefits to the mill, but only these two were used for purposes of this discussion.

Corporate tax rate was assumed to be 40%, and capital depreciation was based on the 5 year MACRS method. The appendices show that the total material and labor cost of upgrading the "Bus A" switchgear was $475,931, while replacing the "Bus A" switchgear would have cost an estimated $763,568.

1) The Bottom Line: Although the first cost savings for the upgrade option using vacuum replacement breakers was significant, this cost savings did not tell the complete story regarding the project's impact on the mill's cash flow. Appendix C shows that the five year impact on Net Profit Improvement for the switchgear upgrade is $601,120 with an Investment Rate of Return (IRR) at 20.5%. Conversely, Appendix D shows that the five year impact on Net Profit Improvement for the switchgear replacement is -$83,948 with a negative IRR at -2.7%. The financial impact of a decision to replace the overdutied "Bus A" switchgear versus the upgrade at IP's Androscoggin mill would have drained overall facility profitability of $685,068 paid out over the course of the next five years.

In today's environment of tight financial controls, industry's senior management has set goals to maintain capital spending, at or below the cost of depreciation. In this example, the switchgear upgrade, with a 20.5% IRR, would have had a reasonable chance for corporate approval as a capital improvement to the mill. The switchgear replacement alternative with a negative IRR would likely be dismissed as a poor investment for the company.

V. CONCLUSIONS

As capacity improvements in North American paper mills are on the increase, so too is the need to increase source MVA and interrupting ratings of main power distribution switchgear. Engineers will continue to be faced with the decision to replace or retrofit overdutied distribution equipment. Although the "lure" of purchasing and installing new equipment is compelling, it can often be the worst possible choice in terms of lost production and mill profits for years to come. Although not all vintage switchgear is created equal, there are several ways to extend the operational life of existing equipment with retrofit or replacement breakers. Mill engineering and management should investigate available switchgear upgrade alternatives carefully before electing to dispose of existing equipment and replace it with new equipment.

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[2] Paul G. Barrett, Brian P. O'Neill, Guy Wilson, "Retrofitting Obsolete 15KV Switchgear For a Pulp & Paper Mill" in IEEE PPIC Conference Record, 1990, pp 67-72.

[3] IEEE Standard C37.59-1997, "Requirements for Conversions of Power Switchgear Equipment", 1992.

[4] ANSI C37.09.05.

[5] Paul G. Slade, "Vacuum Interrupters, The New technology for Switching and Protecting Distribution Circuits", IEEE Transactions, IAS, vol. 3, Nov./Dec. 1997, pp 1501-1511.

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[7] Gabe Paoletti, Alexander Golubev, "Partial Discharge Theory and Applications to Electrical Systems" in IEEE PPIC Conference Record, 1998, pp 124-138.

[8] Dick Erickson, AF&PA, "Capital Effectiveness – The Forest Products Industry Agenda 2020" in TAPPI Engineering Conference Record, 1998, pp 753-781

APPENDIX A: Itemized Material and Labor Costs for “Bus A” Switchgear Upgrade

IP Androscoggin Mill Switchgear Upgrade					
"Bus A" Material & Labor Summary					
Feeder Number	Serviced Mill Loads	Replacement Breaker	Current Rating	MVA Rating	Unit Price
4/5 Aux	Turbine Generator G1 Main	150DHP-VR1000-2000	2000	1000	$22,980
16	Utility Tie Main Breaker	150DHP-VR1000-2000	2000	1000	$22,980
D9	Spare	150DHP-VR1000-2000	2000	1000	$22,980
2/3 Aux	Jay and Livermore Hydro	150DHP-VR1000-1200	1200	1000	$21,420
O	Tie Breaker Otis II Hydro	150DHP-VR1000-1200	1200	1000	$21,420
1	5MVAR Capacitor Bank	150DHP-VR1000-1200	1200	1000	$21,420
6	Water Treatment Plant	150DHP-VR1000-1200	1200	1000	$21,420
7	1 and 2 Woodrooms	150DHP-VR1000-1200	1200	1000	$21,420
8	A Digester/Chip Silo	150DHP-VR1000-1200	1200	1000	$21,420
9	A Bleach Plant & Brown Stock	150DHP-VR1000-1200	1200	1000	$21,420
10	No 1 Paper Machine Dry End	150DHP-VR1000-1200	1200	1000	$21,420
11	No 2 Paper Machine Wet End	150DHP-VR1000-1200	1200	1000	$21,420
12	No 2 Paper Machine Dry End	150DHP-VR1000-1200	1200	1000	$21,420
13	No 1 Paper Machine Winder	150DHP-VR1000-1200	1200	1000	$21,420
14	No 1 Paper Machine Wet End	150DHP-VR1000-1200	1200	1000	$21,420
15	No 1 Power Boiler	150DHP-VR1000-1200	1200	1000	$21,420
19	No 1 & 2 Supercalendering	150DHP-VR1000-1200	1200	1000	$21,420
19A	New Generator Feed	150VCP-W1000-2000	2000	1000	$39,010
19B	Spare for Gererator Feed	150VCP-W1000-2000	2000	1000	$39,010
	Subtotal: Replacement Breakers for "A Bus" Upgrade				$446,840
		Labor and Other Material Costs			
		- Engineering Documentation Labor			$3,040
		- Labor & Testing During Mill Outage			$26,471
		- Bus Bracing Material			$6,259
		- Miscellaneous Material			$3,321
	Subtotal: Material and Labor for Upgrade				$39,091
		"Bus A" Switchgear Upgrade Total Cost			**$485,931**

APPENDIX B: Itemized Material and Labor Costs for “Bus A” Switchgear Replacement

IP Androscoggin Mill Switchgear Replacement (Estimate)			
"Bus A" Material & Labor Summary			
New Switchgear Required Item	Quantity Required	Net Price Each	Extended Net Price
BASE UNIT 2000A 5/15kV	20	$3,171	$63,420
BREAKER 150 VCP-W 1000 1200A	14	$17,900	$250,606
BREAKER 150 VCP-W 1000 2000A	5	$19,363	$96,813
BAR RISERS/2000A BUS	2	$1,522	$3,044
ARMORED CABLE TERMINATION 15KV	1	$233	$233
CABLE ENTRANCE 2000A	1	$1,628	$1,628
SURGE CAPACITOR, 3-PH, 13.8kV	1	$1,881	$1,881
LA STATION CLASS 15KV SET	1	$3,611	$3,611
CT, SINGLE RATIO, STANDARD ACCURACY	16	$169	$2,707
CT, SINGLE RATIO, HIGH ACCURACY	3	$317	$950
VOLTAGE TRANSFORMER 15kV	19	$1,589	$30,199
CPT 1-PH 5kVA 15kV	19	$3,127	$59,405
2 CLE FUSE TRAY, 15KV	19	$2,093	$39,763
BREAKER LIFT DEVICE	1	$1,585	$1,585
GROUND & TEST DEVICE 5/15kV 1.2/2kA , MANUAL	1	$8,228	$8,228
DRIP PROOF ROOF INDOOR	19	$529	$10,043
DOOR GASKETS	19	$21	$399
3-PT LATCH/EACH DOOR	19	$245	$4,663
FLOOR CHANNEL *PER VERTICAL SECTION*	20	$232	$4,644
AC CAPACITOR TRIP	19	$95	$1,813
KIRK KEY INTERLOCK	3	$190	$571
DEVICE NAMEPLATES	19	$53	$1,003
INDICATING LIGHT - STANDARD	19	$29	$559
AC AMMETER & SWITCH	19	$207	$3,933
AC VOLTMETER & SWITCH	19	$207	$3,933
WATTHOUR METER 2 ELEMENT	19	$994	$18,878
VARHOUR METER 2 ELEMENT	2	$994	$1,987
WATT TRANSDUCER, 3P3W 4-20mA,YOKOGAWA	2	$486	$972
MOC SWITCH, 9-POLES	2	$497	$994
TOC SWITCH, 8-POLES	19	$230	$4,378
RELAY 50/51/N, 1-PH, TYPE CO	57	$814	$46,375
RELAY 87T, 1-PH, TYPE HU	2	$3,329	$6,659
Subtotal: Replacement Switchgear for "A Bus" Upgrade			$675,876
Labor and Other Material Costs			
- Engineering Documentation Labor			$7,600
- Equipment Rigging & Rentals			$3,520
- Labor and Testing During Mill Outage			$58,562
- Cable Termination Material			$12,340
- Miscellaneous Material			$5,670
Subtotal: Material and Labor for Replacement Switchgear			$87,692
"Bus A" Switchgear Replacement Total Cost			**$763,568**

APPENDIX C: Cost Benefit Analysis – “ Bus A” Switchgear Upgrade

IP Androscoggin Mill *Cost Benefit Analysis - "Bus A" Switchgear Upgrade*

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Investment (Capitalized/Amortized)							
Capital Expenditures							
"A Bus" Upgrade Materials	($446,840)						
Other Material Costs	($6,259)						
"A Bus" Upgrade Labor	($29,511)						
Subtotal	($482,610)						
Total Capitalized/Amortized	($482,610)	$0	$0	$0	$0	$0	($482,610)
Investment (Expenses)							
Expenses							
Mill Downtime (14hrs @ $40,000/hr)	($560,000)						
Miscellaneous Expense	($3,321)						
Subtotal	($563,321)						
Depreciation:		($96,522)	($154,435)	($92,661)	($55,597)	($55,597)	($454,812)
Amortization:		$0	$0	$0	$0	$0	$0
Total Expenses:	**($563,321)**	**($96,522)**	**($154,435)**	**($92,661)**	**($55,597)**	**($55,597)**	**($1,018,133)**
Benefits (Net Cash In)							
Revenue Increases							
Production Improvements During Steam Turbine Maintenance Every 2 Years (96hrs @ $10,000/hr)			$960,000		$960,000		$1,920,000
Subtotal		$0	$960,000	$0	$960,000	$0	$1,920,000
Cost Savings							
Energy Savings with 10% CL Reactor ($20,000/yr at $30/MWh)		$20,000	$20,000	$20,000	$20,000	$20,000	$100,000
Subtotal		$20,000	$20,000	$20,000	$20,000	$20,000	$100,000
Total Benefits:	**$0**	**$20,000**	**$980,000**	**$20,000**	**$980,000**	**$20,000**	**$2,020,000**
Profit Improvement							
Gross Profit Improvement:	($563,321)	($76,522)	$825,565	($72,661)	$924,403	($35,597)	$1,001,867
Less Taxes	($225,328)	($30,609)	$330,226	($29,064)	$369,761	($14,239)	$400,747
Net Profit Improvement:	($337,993)	($45,913)	$495,339	($43,597)	$554,642	($21,358)	$601,120
Add Back Depreciation	($482,610)	$96,522	$154,435	$92,661	$55,597	$55,597	($27,798)
Cash Flow	**($820,603)**	**$50,609**	**$649,774**	**$49,064**	**$610,239**	**$34,239**	**$573,322**
Cumulative Cash Flow	**($820,603)**	**($769,994)**	**($120,220)**	**($71,155)**	**$539,083**	**$573,322**	
NPV	**($820,603)**	**$46,008**	**$537,003**	**$36,863**	**$416,801**	**$21,260**	**$237,332**
IRR:	**20.5%**						
Payback (Months):	**37.4**						
Tax Rate:	40%						
Depreciation Method:	MACRS						

APPENDIX D: Cost Benefit Analysis – “ Bus A” Switchgear Replacement

IP Androscoggin Mill *Cost Benefit Analysis - "Bus A" Switchgear Replacement*

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Investment (Capitalized/Amortized)							
Capital Expenditures							
"A Bus" New Switchgear	($675,876)						
Other Material Costs	($15,860)						
"A Bus" Swithgear Installation Labor	($66,162)						
Subtotal	($757,898)						
Total Capitalized/Amortized	($757,898)	$0	$0	$0	$0	$0	($757,898)
Investment (Expenses)							
Expenses							
Mill Downtime (36hrs @ $40,000/hr)	($1,440,000)						
Miscellaneous Expense	($5,670)						
Subtotal	($1,445,670)						
Depreciation:		($151,580)	($242,527)	($145,516)	($87,310)	($87,310)	($714,243)
Amortization:		$0	$0	$0	$0	$0	$0
Total Expenses:	**($1,445,670)**	**($151,580)**	**($242,527)**	**($145,516)**	**($87,310)**	**($87,310)**	**($2,159,913)**
Benefits (Net Cash In)							
Revenue Increases							
Production Improvements During Steam Turbine Maintenance Every 2 Years (96hrs @ $10,000/hr)			$960,000		$960,000		$1,920,000
Subtotal		$0	$960,000	$0	$960,000	$0	$1,920,000
Cost Savings							
Energy Savings with 10% CL Reactor ($20,000/yr at $30/MWh)		$20,000	$20,000	$20,000	$20,000	$20,000	$100,000
Subtotal		$20,000	$20,000	$20,000	$20,000	$20,000	$100,000
Total Benefits:	**$0**	**$20,000**	**$980,000**	**$20,000**	**$980,000**	**$20,000**	**$2,020,000**
Profit Improvement							
Gross Profit Improvement:	($1,445,670)	($131,580)	$737,473	($125,516)	$892,690	($67,310)	($139,913)
Less Taxes	($578,268)	($52,632)	$294,989	($50,207)	$357,076	($26,924)	($55,965)
Net Profit Improvement:	($867,402)	($78,948)	$442,484	($75,310)	$535,614	($40,386)	($83,948)
Add Back Depreciation	($757,898)	$151,580	$242,527	$145,516	$87,310	$87,310	($43,655)
Cash Flow	**($1,625,300)**	**$72,632**	**$685,011**	**$70,207**	**$622,924**	**$46,924**	**($127,603)**
Cumulative Cash Flow	**($1,625,300)**	**($1,552,668)**	**($867,657)**	**($797,451)**	**($174,527)**	**($127,603)**	
NPV	**($1,625,300)**	**$66,029**	**$566,125**	**$52,747**	**$425,465**	**$29,136**	**($485,798)**
IRR:	**-2.7%**						
Payback (Months):	**65**						
Tax Rate:	40%						
Depreciation Method:	MACRS						