# RESTORATION AND UPGRADE OF A PAPER MILL'S ELECTRICAL GENERATING SYSTEM— A CASE STUDY OF BROWNVILLE SPECIALTY PAPER PRODUCTS


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***Abstract* - This restoration and upgrade project was undertaken based on the need to replace the excitation system, generator protection, synchronizing control and circuit breaker of Brownville Specialty Paper Products' 875 kVA, 480 volt paper mill generator. The project was prompted by an electrical fault, which occurred on the generator feed and resulted in a fire. The fire event is described as well as a fault description and the resulting damage. The general effect of the loss of the steam turbine generator on the mill is discussed, including the incremental energy costs for mill operation. This paper identifies the necessary repairs and replacements required to return the steam turbine and generator to service and thoroughly discusses the mill operational and protection advantages obtained through the upgrade project.**



*Index Terms* – Paper Mill Generator, Generating System Upgrades, Excitation, Protection, Synchronizing System.


## I. INTRODUCTION

Brownville Specialty Paper Products, Inc. (BSPP) was formed in 1991 to purchase and refurbish the former Boise Cascade Specialty Mill in Brownville, New York. Brownville is located near Watertown, New York on the east side of Lake Ontario. BSPP makes a wide range of specialty grades of paper products. BSPP products are divided into four main market categories: office products, graphic arts, specialty packaging and industrial specialties.

The infrastructure of the mill is contained within the original building structure. The electrical distribution system is a radial 480-volt system with an in-house steam-turbine generator. The steam-turbine generator serves multiple purposes for the paper mill including: supply of some of the electrical mill load, maintaining the mill voltage, and most importantly, regulation of the steam flow-pressure for the paper machine. The electrical system is an ungrounded delta. Fig. 1 shows the basic electrical one-line diagram. The mill is tied to the local utility through two parallel sets of three single-phase banks of transformers. One set is rated at 333 kVA per phase and the other at 400 kVA per phase, and the transformer voltage ratings are: 23 kV / 460 volts with one bank of three 400 kVA at 4.8% impedance and one bank of three 333 kVA at 4.86% impedance. The utility tie voltage is 23 kV. There are eight low voltage motors ranging from 150 HP to 250 HP.

The steam-turbine generator is rated at 875 kVA, 480 volt, 0.8 pf, 1200 rpm, and 1050 full load amperes. It is directly connected to the 480-volt mill distribution system. The turbine steam flow rating is 42,000 lbs. per hour. The generator cannot carry the full plant load but does offset some energy requirements as well as provide some reactive support for the induction motor load. The steam turbine's primary purpose is to control the steam for the paper machine. It provides pressure reduction as appropriate in the steam system for the mill process; otherwise a limited pressure-reducing valve (PRV) must be used.

BSPP paper mill's generating system was restored and upgraded after an electrical fault and subsequent fire. This paper details the project including the scope, objectives, and design of the replacement and upgraded protection, synchronizing control, and excitation system.

The resulting benefits of the mill upgrade are presented, including:

- provision of complete, modern electrical protection
- facilitation of unit synchronizing for boiler operators
- vastly improved excitation control for better voltage performance to reduce energy costs and power factor demand

The challenges of keeping the paper mill operational during the installation and commissioning of the new equipment are also provided. The generator was also rewound during this project, but is not discussed in this paper.

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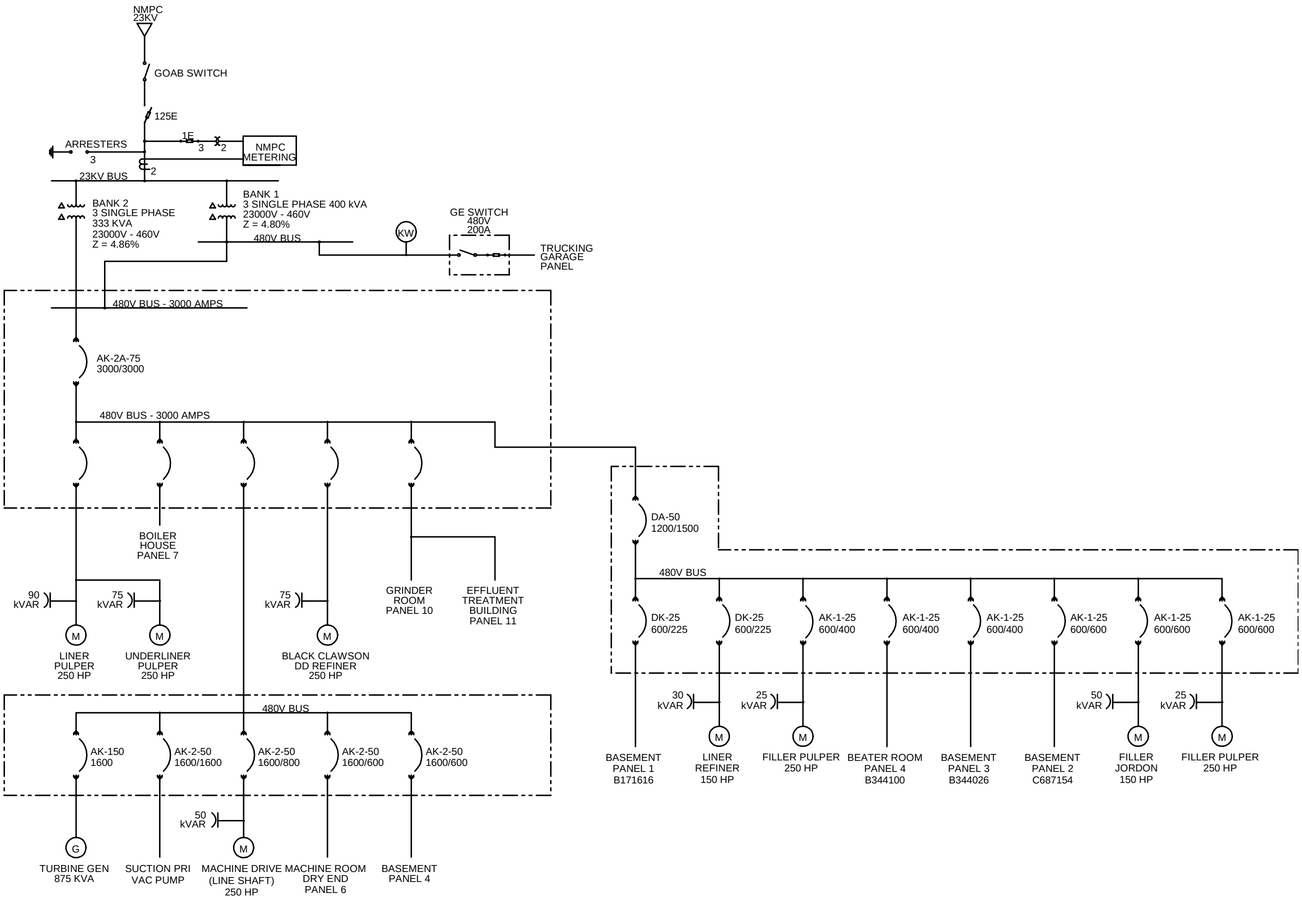


Fig. 1 BSPP Electrical One – Line Diagram

## II. ELECTRICAL FAULT AND FIRE EVENT

On the evening of August 15, 2005, a fault and resulting fire occurred that damaged the 875 kVA generator and its associated equipment. It is thought that the fire was caused by a short—caused by worn or damaged insulation on the six 750 mcm cables running between the generator and the AK1-50 1600 amp breaker that connects the generator to the mill electrical distribution system. This fault was between two phases on this section of cable run. The phase-to-phase fault and its duration caused the contacts on two phases of the generator breaker to weld together and would not allow the generator to be cleared from the mill electrical system. The only protection in place was the breaker's long time element that had significant delay. Therefore, the breaker did not trip prior to the contacts welding together on the faulted phases. The generator continued to feed energy into the fault for some time. This was due to the failed breaker, the lack of an automatic shutdown of the turbine generator system, and the resulting generator decrement current due to the fault. The mill's main 3000-amp breaker was opened and isolated the mill electrical system from the utility supply without incident. When the mill power was shut down, the oil pump feeding the turbine valve controls and field excitation control also shut down. The turbine valve was forced to close, removing the steam supply when the oil supply was eliminated. In addition, the field excitation decayed in time when the control was lost during the mill power shutdown. The generator stopped feeding electrical energy to the fault after the steam and field were removed.

The fire destroyed the voltage regulator and field circuits, the breaker and cubicle, the limited protection, and the synchronizing control. There were four other 1600 amp breakers in the switchgear line-up that also had to be removed, cleaned, and repaired. The bus work and wiring in the switchgear had to be cleaned and repaired before the mill was able to run.

Figs. 2, 3 and 4 document examples of the extensive damage to the equipment and systems in the fire.

Fig. 2 Damaged Breaker Cubicle

Fig. 3 Extensively Damaged Generator Breaker

Fig. 4 Damaged Excitation Control and Synchronizing Equipment and Metering

A service shop performed preliminary testing on the generator stator and field windings using a 1000-volt electrical resistance test (megger) on the generator. The unit passed the test, thereby indicating that the winding was not shorted to ground and it was not a failure of the ground wall insulation. A surge comparison test was also performed on the winding and gave an indication of shorted turns. The service shop recommended a rewind based on this evaluation and the duration of the fault. The field winding was also electrical resistance tested (meggered) at 500 volts; the measured value was low, indicating possibly a dirty winding or a problem with the insulation system. The recommendation from the shop was to clean the field winding and revaluate it for possible rewind. The details of the generator repair are not discussed in this paper.

The generator has a direct-connected rotating exciter. Unrelated to the event, the rotating exciter's commutator was at a point where further undercutting was not practical. Replacement parts and maintenance also had been problematic with this older system. A decision was made to go with a static excitation due to the condition of the exciter and the other above-mentioned issues. Additionally, the superior performance and operational capability of the new excitation system helped justify the replacement. The operational and performance capabilities were integral to BSPP's objectives to upgrade the system.

Due to the extensive damage, the protection, synchronizing control, and excitation control also needed to be replaced. The switchgear cubicles that included the breaker, associated protection, synchronizing and excitation control were damaged beyond repair. Additionally, the generator power lead cables suffered significant damage and needed to be replaced. All associated instrument transformers, control power transformers, protection and control cables were damaged beyond repair and also needed to be replaced.

## III. LOSS OF STEAM TURBINE, GENERATOR, AND ASSOCIATED ELECTRICAL SYSTEM AND SUBSEQUENT IMPACT ON MILL

The turbine is started once at the beginning of the workweek and operates for six days, three shifts a day, 24 hours a day. It typically supplies 300 kW to the mill load, offsetting energy costs as well as supporting reactive power needs for the induction motor load. The average reduction in energy costs is several thousand dollars per month. The power factor for the mill without the unit on-line is typically 0.8 to 0.9 pf lagging with a power factor demand charge from the electric utility.

Most important to the mill is the need to provide steam flow control for paper production and pressure reduction for the steam utilization by the plant using the turbine. As the colder months approach, having the unit out of service would have a significant impact on the steam process operation and thus production; therefore, it was paramount that the unit was returned to service as soon as possible. The estimated reduction in steam flow was 70% when the PRV was used instead of the turbine.

## IV. REPAIRS AND REPLACEMENTS TO RETURN STEAM TURBINE GENERATOR TO SERVICE

The generating unit and associated equipment were more than 50 years old. Because the equipment had this service life, and continued to be a significant part of the productivity (steam process) and economic efficiency of the paper mill operation, a refurbishment/rewind was chosen.

All of the associated generator system equipment damaged in the fault/fire event was replaced and upgraded to state-of-the-art systems. The rotating exciter was replaced based on its age and due to the inability to further undercut the commutator for additional service life. Due to the fire, the excitation controls were damaged beyond reuse. A static excitation system including the voltage regulator was provided; significant performance as well as greater flexibility in operation was obtained.

The protection and synchronizing systems were damaged as well and replaced. A current state-of-the-art generator protection system would provide significantly better and more comprehensive protection for the generator and its systems, including fast fault protection. This package brings the generator protection up to current industry recommended practices. The IEEE Guides addressing this subject are cited in the references and are IEEE C37.102-1995 "IEEE Guide for AC Generator Protection" [1] and IEEE 242-2001 "IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems" [2]. This type of protection system can prevent, or at least minimize, damage if a similar event occurred by sensing the fault quicker and taking action sooner.

Replacing the manual method of synchronizing with an automated system would facilitate bringing the unit on-line at the beginning of each workweek or as necessary. Using an automatic synchronizing system would greatly reduce the complexity of connecting the generator to the electrical system and the potential for errors when synchronizing the unit. This will reduce concerns for the mill operators and the likelihood of a damaging synchronizing event. Synch check supervision was also added to this system.

These recommendations were financially supported, based on BSPP's incremental energy and power factor demand monthly charges being several thousand dollars and the steam production being impacted up to 30 percent during the cold months without the benefit of the turbine/generator operation. The payback period on energy costs alone was estimated at 25 months, which was concluded as reasonable.

## V. UPGRADE PROJECT OBJECTIVES

The project had the following BSPP required objectives:

1. Design the new retrofit systems to replace the existing damaged excitation system, protection, and synchronizing control. This would be accomplished by both cleaning existing cubicles and as much of the electrical system as possible and applying modern technology and systems as required.
2. Provide automation via a lockout relay that would trip and shut down the unit for abnormal operation and fault conditions.
3. Facilitate the process of bringing the unit on-line and synchronizing for the boiler operators by providing improved synchronizing control. Automate as much of the process as possible. Synch-check supervision would also be applied.
4. Improve the excitation control for better mill voltage performance to result in reduced costs of energy usage and power factor demand. This would be accomplished by including automatic voltage regulation capability of the static excitation system.
5. Provide a more reliable and complete protection system for the mill's turbine-generator based on current technology and industry recommended practices. This would help mitigate any future occurrences of electrical faults evolving into fire events. Additionally, this system would greatly reduce the extent of damage and equipment loss.

## VI. DESIGN OF REPLACEMENT PROTECTION, CONTROL, AND EXCITATION SYSTEMS

As stated, as much of the existing infrastructure and equipment was reused. The excitation system was essentially replaced with a static excitation system, shown in Fig. 5. A new cubicle containing this system was installed next to the existing switchgear line up.

Fig. 5 Static Excitation System

A digital Integrated Protection System was applied to provide the generator protection. The following protection functions were implemented:

<u>ANSI Device Number</u>
25 – Synch Check Supervision Protection
27 – Undervoltage Protection
32 – Reverse Power Protection
40 – Loss of Field Protection
46 – Negative Sequence Current Protection
47 – Negative Sequence Overvoltage Protection
51V – Voltage Restrained Overcurrent Protection
59 – Overvoltage Protection
60FL – Fuse-Loss Protection
81 – Over/Under frequency Protection

An engineering consultant provided the settings that were applied to the Protection System.

For the automated synchronizing system, a Synchronizer Unit and a Generator Control Unit were implemented. This package provided complete automation of the run-up, synchronizing, and closing of the generator breaker with supervision by synch-check function 25 from the generator protection system. Due to the lack of electrical control on the turbine governor (presently pneumatic), only the run-up of the voltage regulator and the closing of the generator breaker are fully automatic. The turbine generator speed is still manually run-up by the operator with the pneumatic control and then, once at speed, the system automatically properly closes the breaker. BSPP plans on replacing the governor control in the future to completely automate this process for the operators. Yet, compared to the old manual process, this system helps the operators by facilitating the start-up process and greatly reducing the exposure to synchronizing errors and equipment damage.

Another key addition was the automated shutdown/tripping of the unit during a fault or abnormal operating condition. A lockout relay was added that simultaneously trips the generator breaker, shuts down the excitation system, and closes the turbine main stop valve—completely removing the unit from operation. This is superior to the existing manual shutdown approach used especially during emergency situations like the August 15th event.

Fig. 6 shows the internal sub panel mounted into the cleaned switchgear cubicle. This panel includes the instrument transformers and interconnecting terminals for field wiring and other interconnections between systems.

Fig. 6 Internal Sub-Panel for Protection and Control Circuits

In Fig. 7, the back of the protection and synchronizing control system sub-panel is shown mounted into the cleaned front door of the switchgear.

Fig. 8 shows the front view of the new completed protection and synchronizing control equipment mounted on the switchgear door. This includes the digital Integrated Protection System, Synchronizer Unit, Generator Control Unit, synch scope, metering, and control switches.

Fig. 7 Back of Protection and Synchronizing Control Sub-Panel


Fig. 8 Front of the New Protection and Synchronizing Control Sub-Panel Installed

An uninterruptible power supply (UPS) system was provided and is shown in Fig. 9. This system was added to provide emergency power to shut down the unit in the event of the loss of plant power. Adding this UPS enhances the protection and safe shutdown of the turbine-generator and associated equipment.

Fig. 9 UPS System Installed in Switchgear Cubicle

Fig. 10 shows the overall completed retrofitted switchgear with the new systems. Using sub-panels with self-contained wiring facilitated the field installation as the wiring in the sub-panels was completed and checked out in the factory. Only the field-run wiring and interconnections needed to be completed and checked out in the field. This expedited the work in the field tremendously and left less room for error.

Fig. 10 Completed Retrofitted Switchgear Showing Excitation, Protection and Synchronizing Control Systems

Fig. 11 shows the overall one-line diagram of the generator protection and synchronizing control systems. Included is the ANSI Device #86G lockout relay that implements the complete shutdown/trip of the unit discussed previously.

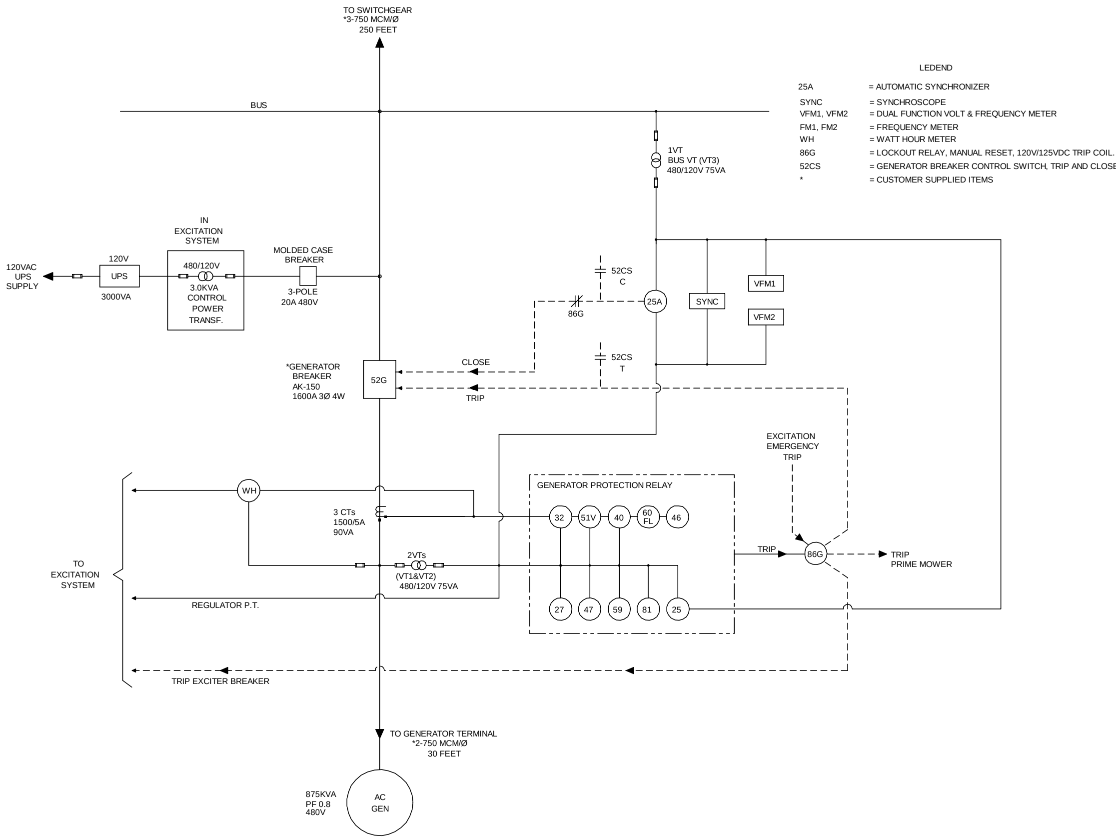


Fig. 11 One-Line Diagram of Generator Protection and Synchronizing Control System

## VII. INSTALLATION AND COMMISSIONING OF THE UPGRADED SYSTEM

The challenge during installation and commissioning was to integrate the generator system while the mill was in operation producing paper. Essentially, all phases of the installation and commissioning were conducted in parallel including phasing of the generator with the electrical distribution system. Double and triple checks were conducted to ensure no errors would jeopardize the mill‘s electrical system or production.

Field wiring was installed and checked out by BSPP and their electrical contractor per the design drawings. The manufacturers' engineers also verified the wiring when on-site.

All control and trip circuits were set up and checked prior to being connected to the electrical system. Breaker closing time measurements were conducted to determine the proper settings for the Synchrocloser Unit. Phasing of the generator and the electrical system were determined and compared to ensure proper relationship prior to closing the breaker.

The unit was brought up, synchronized, and connected without any problems for the first time on February 3, 2006. At the same time, a field engineer from the manufacturer performed the commissioning and tuning of the static excitation system within a few days.

In general, the installation and commissioning of the new systems and rewound generator were completed without any impact to the mill.

## VIII. CONCLUSION

This project was completed approximately five and a half months after the fault and fire event occurred. The BSPP mill is back running at 100 percent production, making full use of the turbine generator. The fundamental reason for the success of this project was a cooperative, full-team effort between BSPP and manufacturers of the generator protection, synchronizing, and static excitation systems.

A check of the power factor of the electrical system at the utility yielded a unity power factor when the generator was operated, while providing appropriate voltage regulation of the 480 volt system. The synchronizing system has been used by the operators a number of times and has performed well.

Due to paper machine problems and loss of steam, the unit has actually been tripped on reverse power with the complete shutdown logic working properly.

The key dates for the project progression were the following:

9/23/05 - Generator sent out to Service Shop

1/4/06 - Generator returned to site

1/11/06-1/25/06 - New controls on sub-panels installed

Week of 1/25/06 - Engineers on site to help with installation, check out, and commissioning

2/3/06 - Generator commissioning complete and on-line running at noon

If a fault were to occur similar to the August 15, 2005 event, the over-current protection will quickly detect this fault condition and initiate a tripping of the breaker as well as a complete shutdown of the turbine and excitation systems. The fault damage would be greatly reduced and the potential for a fire minimized. Prior to this upgrade, there was no automatic or fast acting means in place—setting the stage for the significant damage and fire that occurred. Impact to the mill production would also be significantly reduced.

In summary, the following benefits were derived:

1. More complete and current protection and control
2. Facilitation of the unit start-up and synchronizing for the operators
3. Automatic shutdown of the unit during faults or abnormally operating conditions
4. UPS for emergency power for safe shutdown with loss of normal control power
5. Extensive on-line metering/monitoring, data capture, and sequence of events
6. State-of-the-art voltage regulation for the 480 volt system using the static excitation system
7. A payback period of a little over two years for the complete project

## IX. REFERENCES


[1] IEEE C37.102-1995, *IEEE Guide for AC Generator Protection*, New York, NY: IEEE.

[2] IEEE 242-2001, *IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems*, New York, NY: IEEE.