Selecting the Excitation System for the Additional Turbine Generator at the Port Wentworth Pulp Mill

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Abstract: Weyerhaeuser Company owns a market softwood pulp manufacturing facility at Port Wentworth, GA and the company was looking for a way to reduce manufacturing costs. It was determined that if a used steam turbine generator could be installed at the plant, this would be a viable way to reduce manufacturing costs. The unit would displace purchased electrical energy with “in house” generation during times that the plant could produce the energy for less than it would be charged by the electric utility. During these times, the unit would be operated in a mode such that the electrical energy flowing into the plant through the utility intertie would be kept to a minimum (tie line control mode). During other times of the year, providing that it was economical, the plant could sell electrical energy to the utility. Once the unit was purchased and the degree of reconditioning and repairs to the turbine and the generator had been determined, the next major decision was which of the auxiliary systems could be re-used.

This paper covers the process involved in evaluating whether or not to reuse the generator's original compound excitation system and if replaced, the type of excitation system that should be installed, Compound or Potential Bus Fed Type. Discussed are the issues encountered during the evaluation process, the expectations desired, the decisions made and the outcome achieved as a result of the final decision to replace the existing compound excitation system with a potential bus fed excitation system.

PROJECT SCOPE

Weyerhaeuser Company's Port Wentworth facility manufactures softwood market pulp. The heart of the plant's utility system is the Recovery and Utility Complex consisting of two large 600 psig, 750° F boilers and a radially configured, 13.8 kV, electrical power distribution system (PDS). The PDS consists of 1000 MVA, 15 kV switchgear, a 30 MVA, 46/13.8 kV utility tie and a 56 MVA, 13.8 kV single extraction, back pressure turbine generator (#4 TG). One boiler is a base loaded 450,000 lb/hr recovery boiler. The other boiler, which is a combination unit, is rated 500,000 lb/hr (on gas or oil)/400.000 lb/hr (on just bark) and operates as the swing unit. The plant's electrical load is approximately 30 MVA. In recent years, the plant has shut down a linerboard machine, as well as the complete pulp mill and parts of the wood handling facility that supplied it. While this left the plant with an excess of steam capacity, the plant still must regularly buy some 6 to 8 MVA of electrical energy. This occurs because the output of the #4 TG is a function of the connected process steam demand flowing through its turbine. Since a large portion of this steam load “disappeared” with the above mentioned shut downs, the #4 TG is not able to produce the plant's entire electrical requirement. By adding a condensing turbine generator unit to the plant, the generator could supply the “shortage” as well as take care of electrical load swings and even regulate the plant's voltage should it ever become disconnected from the utility.

It was determined that if a used condensing steam turbine generator, in good condition (hereafter referred to as the new turbine generator, new unit, or TG#5) could be located, tested, purchased and installed, this would be a viable way to help cut manufacturing costs at the Port Wentworth facility. The new generator, which would supply the plant's additional electrical demand, would be operated in a tie line control mode with a set point of zero MW. This mode of operation would keep the incoming electrical energy flowing through the utility tie at or near zero. At just how close to ‘zero flow’ the tie would remain would depend on the new unit governor's dead band and the time constant of the new turbine's overall speed control system. The new unit would operate in this mode during the parts of the year when “in house” electrical energy costs were less than those charged by the electrical utility. During the balance of the year, should it prove to be profitable, the plant's contract with the utility would allow it to sell excess electrical energy to the utility.

A project scope was defined and funds were approved. The major components of the project to be installed at the plant consisted of the turbine, the generator and the infrastructure to support and connect the new equipment to the Recovery and Utility Complex. In addition, there were many auxiliary systems required to support the turbine and the generator such as:

1. Turbine stop valve and its controls
2. Turbine control valve and its actuator
3. Turbine condenser including large condensate recirculation pumps
4. Turbine drain and leak off system
5. Turbine governor
6. Turbine control panel
7. Turbine supervisory instrumentation system
8. Two cell cooling tower with variable speed fans
9. Generator excitation system
10. Generator grounding system
11. Generator protective relaying system
12. Generator supervisory instrumentation system
13. Generator control panels - both local and remote
14. Generator's hydrogen cooling system including its control panel
15. The combination lubrication, bearing sealing and hydraulic control oil system
16. Turning gear assembly and its controls

Although the generator met or exceeded acceptable electrical test criteria, the unit was approximately 35 years old. The project scope did not include funds for a generator stator rewind. However, funds were available for the rotor rewind, if necessary.

Discussions were conducted with the plant's major loss carrier and several generator specialists in order to determine a “course of treatment” for both the stator and the rotor. All agreed that the generator stator windings had exceeded their “design life” (30 years), but in view of the test results obtained prior to purchasing the unit, the unit should still have "some" useful life left.

It was decided that a minimum “clean up” was all that would be done to the stator winding before re-energizing the generator. It was a calculated risk, but the project team felt that conditions were favorable, although there was no guarantee that the unit would continue to operate with its present windings long enough to obtain the project’s anticipated return on investment.

Fig. 1: New Turbine Generator and Reactor installed at the Recovery and Utility Complex

Similarly, the generator rotor met or exceeded acceptable electrical test criteria. Hence, it was decided to send the generator's rotor out to a machine shop to have its collector rings resurfaced, its wedges re-tightened and the complete rotor re-balanced. Similar refurbishment was done to the turbine rotor, the turbine stop valve and control valves along with the control valve's actuator.

Once the above decisions were made with respect to the turbine generator proper, the major remaining consideration was whether or not to just reuse, re-condition and reuse, or replace all the various auxiliary systems. These decisions were made on a system by system basis.

The Turbine Generator System

The turbine generator (unit) that was obtained for the project was manufactured circa 1967. It has a condensing turbine with four uncontrolled extraction ports and was originally rated 22,000 kW. Its synchronous generator is a hydrogen cooled unit originally rated 29.4 MVA with a power factor of 0.85 and a nominal stator voltage of 13.8 kV. The generator's rotating field is rated 409 amps at 250 volts DC (102) and originally supplied, via collector rings, from a compound excitation system.

Fig. 2: Turbine Generator Undergoing Inspection and Test Prior to Purchase

The purchased system also included all auxiliary systems for both the turbine and the generator. Since its installation in 1968, the unit had been operated as a base loaded unit for a utility located in the Great Lakes region. The unit operated nearly continuously until 1993 when it was shut down for a modernization and a major re-rate of the turbine. Its turbine was mechanically rebuilt and re-rated to 29,000kW thus allowing the generator to develop and deliver its full range of capabilities. At the same time, the original hydraulic governor was replaced with an electronic governor and both the turbine and the generator were extensively instrumented with temperature and vibration probes, all of which reported to a new supervisory control system and data logger. The generator rating remained the same.

The unit was re-commissioned, again as a base loaded unit, and ran until 1997 at which time the entire plant was decommissioned and shut down. The three turbine generator units at the plant were mothballed by having the turbine generators enclosed, on the operating level, in electrically heated enclosures of closed cell foam. The units had desiccant strategically placed within the enclosures to keep the units dry. At some time subsequent to the decommissioning of the plant, all power to the plant was shut off and subsequent changes of the desiccant were suspended resulting in the turbine generator units lying fallow.

During the month of October 2002, the owner was contacted. With certain preconditions having been met, the unit was torn down, inspected and tested with the aid of a temporary electrical generator (and a constant voltage transformer to run the test equipment), a DC welder to dry out the windings prior to testing and kerosene heaters to remove moisture from the immediate area of the generator windings. This was done as the temperature outside (and subsequently, inside) the plant began to drop in preparation for greeting the upcoming “Great Lakes” winter.

Subsequent to satisfactorily passing both mechanical and electrical inspection and testing, the unit was purchased in early November. The collecting of the engineering and manufacturer's drawings, the tagging of equipment, the disassembly and packing the parts and pieces into shipping containers began in earnest during November and continued into mid December of 2002. The containers were shipped to site at Port Wentworth and arrived during the month of January 2003.

DESIGN CONSIDERATIONS

Although the design work on the project began in November immediately after the unit had been purchased; the design process and all the associated decisions were exacerbated by several factors. These included:

1. The time table and the method used to de-terminate the equipment while still in storage allowing little opportunity either to investigate the original equipment interconnections or to properly label them
2. The existing documentation and spare parts were found in a state of "disarray".
3. Once the existing engineering and manufacturer's documentation was reviewed, sorted, and labeled with project equipment numbering, it needed to be entered into a project database.

The project team faced an extremely aggressive project timetable since the most expensive electrical energy that the plant purchased was the energy delivered during the warm months of the year, i.e., from June through September. The plant wanted the unit operational as soon as possible after June 1, 2003. While this commissioning date was considered unachievable it was incumbent upon the project team to make decisions in a very timely manner in order to achieve the unit's commissioning at the earliest practical opportunity to maximize the Company's return on its investment.

EVALUATION PROCESS FOR TYPE OF EXCITATION SYSTEM

As mentioned previously, the first consideration with regard to the unit's excitation system was whether to reuse, recondition and reuse, or replace the compound excitation system. The decision process included evaluating the pros and cons of reusing the existing excitation system. The pros and cons are listed in Table1.

Pros	Cons
1. In all probability, reusing the equipment would result in the least capital cost.	1. The equipment was on the manufacturer's "Obsolete Equipment List" resulting in parts not being readily available from the manufacturer and, more than likely, technical service would not be available in a timely manner
2. Parts were available from after market suppliers.	2. The equipment contained parts that had very long lead times, namely power saturable current transformers, which would require 17 weeks to replace if they failed. 3. The existing regulator was an analog regulator subject to the normal component value drifting due to both temperature variations and aging. 4. The MVA capabilities of the generator could be extended via better protection and limiter circuitry. 5. Overexcitation limiting used to prevent rotor overheating is not available with the existing system, while the generator protection is limited to generator field overvoltage or Volts/Hertz. 6. Manual control does not track the voltage regulator, hence transfer to manual control could cause a system upset if not continuously monitored by the operator. 7. Increased automatic control via Distributive Control System or PLC cannot be supported by the existing hardware. 8. Systems now require better operating performance and better response time for improved transient stability. 9. Cleaning existing equipment to determine if it were still operational would take a great deal of engineering time and construction effort, which translated to a substantial cost with the possibility of little or no return.

Table 1: Items considered in the evaluation of whether or not to reuse the existing excitation system

After evaluating the pros and cons it was decided that the existing compound voltage regulating system should be replaced. The next decision was to decide which type of voltage excitation system to employ – a compound type or a potential bus fed excitation system.

THE EXCITATION SYSTEM

The compound type excitation system combines an output from a power potential transformer (PPT) connected to the generator high voltage terminals combined with the output from power current transformers one in each phase of the generator. The combined output of the PPT with the power current transformers provides a vector addition of voltage that is rectified via an SCR controlled rectifier bridge and applied to the field of the generator. An automatic voltage regulator monitors the terminal voltage and determines the amount of power to be applied to the field of the generator to maintain constant output at the generator. Should a fault occur in the power distribution system, the compound excitation system is designed to provide current support typically for 10 seconds depending upon the design characteristics of the machine in order to provide enough time for the generator protection to clear the fault. See ANSI C50.13.

During a fault, the generator terminal voltage will dip depending upon the impedance between the generator and the location of the fault. See Fig. 3. With a compound excitation system, the fault current produced by the generator will supply power to the excitation system via the power current transformers to supply power to the field of the generator thus maintaining the fault current for enough time to provide relay coordination for breaker tripping.

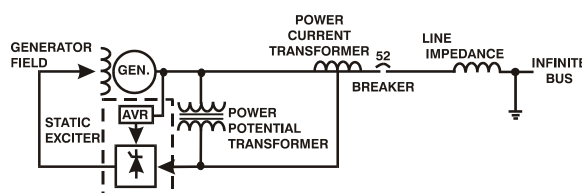

Fig.3: Simplified Compound Excitation System

Where nearby generation can provide the fault current or it can be provided by careful coordination of the protective relaying in the plant, a compound excitation system may not be required.

Compound excitation systems were very popular in the early '70s and before, prior to the utility network interconnected systems where fault current could not be derived by other sources.

A potential bus fed excitation system is unlike a compound type static exciter because it utilizes only a PPT connected to the generator terminals to provide excitation power. See Fig. 4.The output of the power transformer is connected to a 6-thyristor power bridge that is controlled via a firing circuit and voltage regulator.

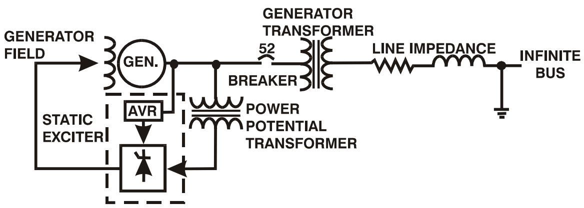

Fig. 4: Simplified Potential Bus Fed Excitation System

The bus fed excitation system is designed to provide a level of field forcing that exceeds the nominal requirements of the field during steady state loading at rated kVA and rated power factor. Typically the field forcing level is a minimum of 150% of the nominal full load requirements, reference IEEE 421.4. During a fault, the voltage to the power bridge will drop by the percentage of the voltage drop at the generator terminals. Hence if the terminal voltage drops by 30%, the bus fed excitation system would still be able to deliver 105% field excitation based upon 150% field forcing.

For the new Port Wentworth generator, the full load field amperes are 409 amperes with a hot field resistance of .485 ohms. This results in a field voltage of 185 Vdc for a 320 Vac nominal PPT secondary. The 6-SCR bridge has a nominal 250 Vdc rating with a maximum field forcing voltage of 375 Vdc or 2.02 P.U. from nominal full load voltage. The high field forcing will result in extremely fast voltage response, as noted in Figure 8. Additionally, should the terminal voltage drop to 70%, the exciter system would still be able to provide 140% field forcing.

Another important consideration of one type excitation system versus the other is cost. The potential bus fed excitation system is approximately half the cost of the compound excitation system and with field forcing of the magnitude discussed above, the risk of insufficient fault current support for the system is minimized.

It was decided that since the original plant generator (G4), was rated 56 MVA with a brushless exciter and a PMG (Permanent Magnet Generator), fault current could be provided from this machine if it became an issue of concern. It was felt a compound system was not required and a potential bus fed excitation would be suitable.

Although not specified, the new excitation system would be digital, based upon a microprocessor design and taking advantage of enhanced features that would allow maximum use of the machine capability and unit field protection. These features would include under and over excitation limiters, volts/Hertz limiter, and auto tracking between voltage regulator and manual control for bumpless transfer. Protection included, field over current and field over voltage, loss of field and automatic transfer to manual control in the event of loss of voltage sensing.

The new static exciter was specified to require 1/4% voltage regulation and a field current regulator for commissioning. Other control modes found to be advantageous were Var and Power Factor control. The Var/PF control acts as supplementary loop controller that allows the voltage regulator to respond quickly after a fault, but as a supplemental control, it will slowly integrate the Var or Power Factor setpoint back to normal after the system recovers from the disturbance. The use of Var/PF control would enable the operator to maintain constant vars without constant monitoring. See Fig. 5.

Figure 5 highlights the controls via contact inputs or RS 485 serial communication port for connection to a DCS control system for operation of the excitation/generator system. For startup and shutdown, the excitation system included an ac field breaker to interrupt the power input to the 6 SCR rectifier bridge. A field flash contactor with a series resistor is used to initiate and automatically build generator voltage initially during starting. An automatic disconnect opens the field flash contactor when the generator voltage reaches a preset voltage level. A field discharge resistor combined with two power SCRs, connected anti-parallel is used to discharge the field energy when the ac field contactor is opened at shutdown.

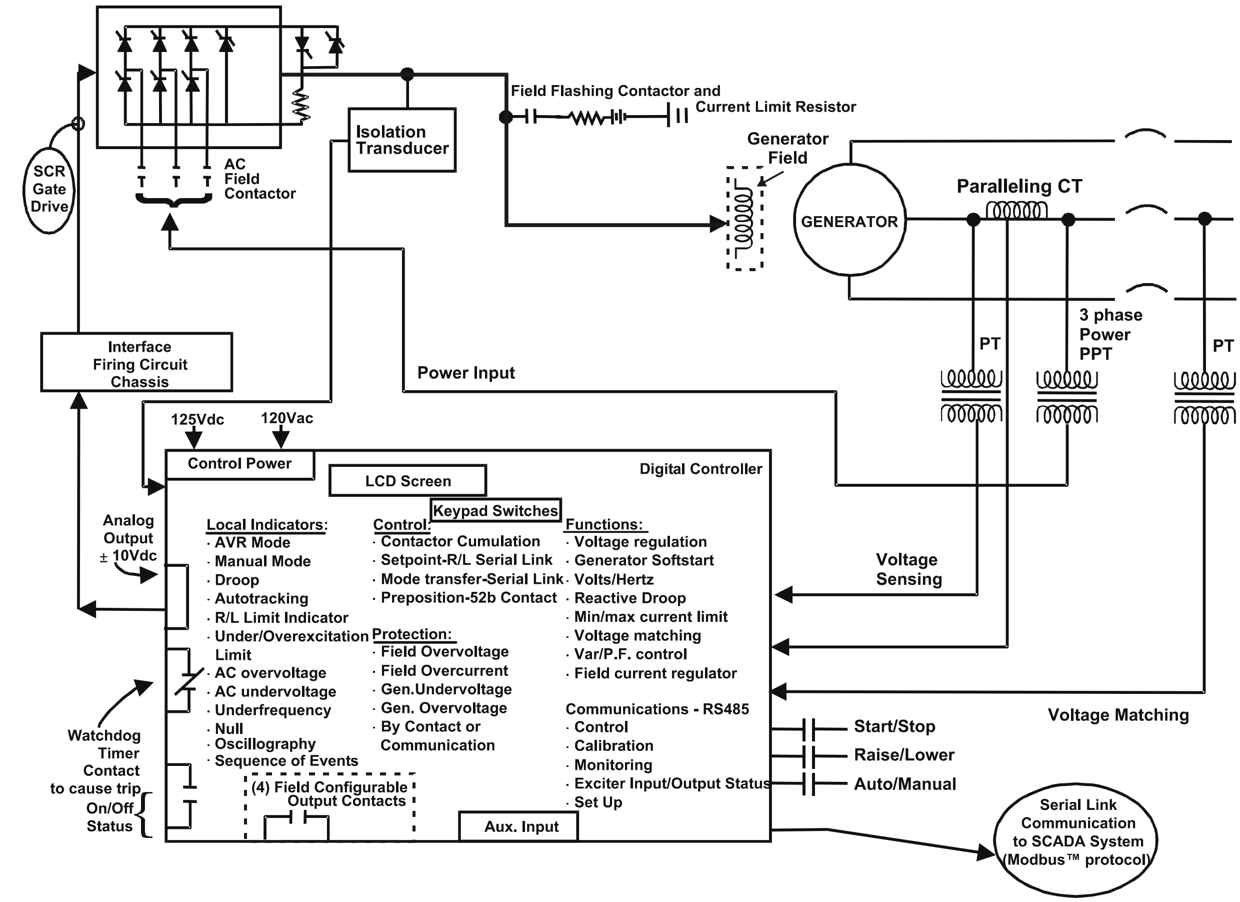

Fig 5: Block Diagram of the Static Exciter System

The new excitation system included voltage matching to eliminate the need for the operator to adjust the generator voltage raise/lower controls to match the bus voltage. The use of the voltage matching feature would speed the process of having the generator synchronize to the bus and ensure the generator voltage is higher than the bus voltage to ensure vars would be exported at time of synchronization.

With future requirements imminent by NERC (North American Electric Reliability Council) an important feature noted was oscillography and sequence of events with the new excitation system. With the new equipment, events such as disturbances could be logged automatically for any system abnormality, including terminal voltage, line current, field voltage and field current, vars, kW etc. in a comtrade file for download into a viewing software program. Sequence of events could provide continuous monitoring of the excitation system for any change with a date and time stamp to help diagnosis problems in the system.

Design Effort

For this project, Weyerhaeuser Company would contract out the design interface of the excitation system. The contractor would provide a detailed bill of material including cabling and routing and terminations, design interface drawings, system elementaries, excitation equipment, checkout and commissioning of the excitation system plus training to plant operators.

Weyerhaeuser decided that it would provide all labor necessary to install the new equipment and provide project supervision at installation.

Rather than being shutdown driven, all of the tasks needed to be defined to fit into a project timeline determined by the time allotted for engineering and construction. This includes such tasks as equipment manufacturing and delivery, interface design, ordering of installation materials, equipment delivery, installation, system testing, system startup and commissioning, training, and documentation. For this project, a schedule outline of how the job would be performed was provided. This included:

An initial meeting between Weyerhaeuser and the consultant was scheduled to convey the needs of both parties to make sure a complete understanding of the project and all expectations were understood. Items that were discussed included:

1. Schedules - To establish new equipment availability, demolition, and removal of the

old equipment and installation of the new systems.
2. Project responsibilities and contacts are established.
3. Functional review of operation of the new upgraded excitation system.
4. Review - Construction procedures and site safety issues.
5. Review - Location of the new equipment.
6. Review - All drawings (system elementaries, connections, and interconnections) of the existing system.
7. Review - Generator design data and curves.
8. Discuss - Conduit runs or to find the optimum direction for new cabling, conduit, and wire tray.
9. Review - Operator interface to the new upgraded excitation system, type of control, digital interface or contacts, alarms, and interface.

Installation Considerations

There were several major installation considerations involving the generator's excitation system that needed to be resolved prior to starting the detailed design. They were the location of the primary components, the location of the operator interface controls and the methodology of interconnection wiring.

It was decided to mount all the major components in a new air-conditioned electrical equipment room (EER) that had its make up air charcoal filtered. This served a dual purpose. First it kept the major components (the PPT and the exciter control/ rectifier cabinet) close to the generator thus minimizing the length of both the PPT and CT sensing leads; and second it supplied a decent environment for the electronics present in the control/rectifier cabinet.

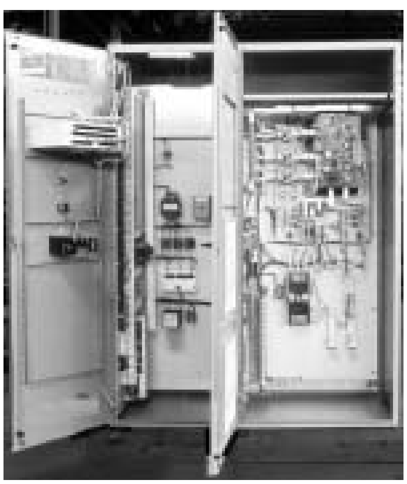

Figure 6: Excitation cabinet installed in the new Generator EER

While the state of the art in the control of today's excitation systems is typically an HMI panel where both alpha numerics and graphics are easily displayed, it was felt It that certain functions such as voltage adjustment and synchronizing were better accomplished using traditional operator interface controls such as rheostats and control switches. Likewise, it was felt that the operators would be much more comfortable with traditional analog metering for the critical generator parameters such as AC Volts, AC Amps, DC Volts, DC Amps, AC Kilowatts and Kilovars even though these parameters would be displayed on the HMI. It was decided to mount both the operator interface controls, the redundant analog metering, and the HMI for the exciter in a new cabinet, designed as part of the project, which would be located in the control room in a space between the existing synchronizing panel and the control cabinet for the existing No. 4 TG. This cabinet would also contain an HMI for the new turbine's governor as well as additional turbine controls and status indication.

The quantity and type of interconnecting exciter wiring was specified by the engineering company who provided the design interface. The construction methodology chosen was one that the Weyerhaeuser design team had used successfully on numerous projects. The AC and DC power wiring was armor sheathed cable in aluminum cable tray. The 120VAC control and 5A CT secondary wiring were installed as singles in aluminum conduit and the analog wiring was individually twisted, shielded triads in rigid galvanized steel conduit. The conduits and cable trays exited the EER walls through an aluminum bulkhead that allowed proper sealing of the EER with regards to the HVAC system.

Commissioning

Upon verification of all ac & dc control circuits, checkout and calibrating of the excitation system began. Interface operating software provided by the manufacturer was used to calibrate the new excitation system. The operating software included means to set both the maximum and minimum limits for the upper and lower voltage raise and lower stops, current levels for over and under excitation current limits, as well as the volts/Hertz value (limit). Absolute values for reading generator voltage and current were accomplished by identifying the generator PT and CT ratios and entering them into the manufacturer's Operating Interface Software.

Testing to check the new excitation system voltage response was accomplished by using an Analysis Test software program and the oscillography recording capability provided with the excitation system. As shown in Figure 7, data logging would capture information of the excitation system performance such as the field voltage, and generator voltage at startup. Figure 7 illustrates the generator voltage buildup characteristic programmed for a 30-

second voltage buildup time. No voltage overshoot occurs using the softstart characteristic.

Figure 7: Voltage Softstart Buildup Characteristic

Performance of the generator and excitation system is a function of the gains that are applied to the digital controller and the available field forcing provided by the power rectifier bridge and the PPT. To measure performance, voltage step changes are performed to record generator voltage response. Figure 8 illustrates the results of a 5% voltage step changed performed when the generator is open circuited. The voltage time recovery is less than .8 seconds with no voltage overshoot.

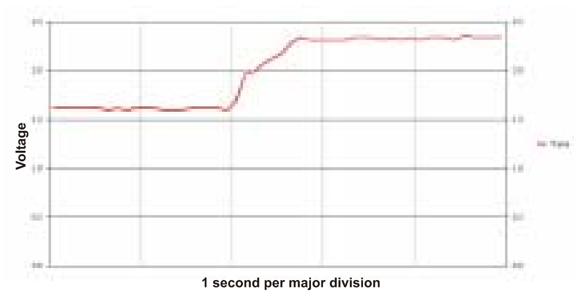

Figure 8: 5% Voltage Step Change

Among other tests performed were verification of both the over excitation and the under excitation limits. The over excitation limit was set to allow maximum field forcing for improved transient stability yet still provide protection of the generator rotor to by preventing excessive heating due to excessive field overload. The under excitation limit was set based upon the generator's reactive capability. It was set to prevent too few vars from being absorbed by the generator for a given number of kW going out of the generator. Too little vars being absorbed for a give KW output would result in the generator slipping poles. The volts/Hertz limit was calibrated to coordinate with the volts/Hertz relay, device 24.

One specific test requested by the mill was to dynamically demonstrate that the automatic voltage regulator would transfer to manual control (field current regulator) in the event of loss of voltage sensing to the automatic voltage regulator. Here, all three sensed voltages were removed by pulling the fuse block to the voltage regulator. Time delay to transfer to manual control was set for .2 seconds, during the interim, voltage rose to 125% and upon transfer to manual, settled back to the prefault condition of 13.8 kV. The test demonstrated anticipated performance.

Conclusion

While at this writing the No. 5 TG has only been running for approximately one week, the check out of the excitation system went extremely smoothly and rapidly.

Both the digital regulator and the power electronics appear to be "rock solid" and have operated as expected. The communications between the main cabinet and the HMI located in the control room have been adequate. A possible area of improvement of the equipment is that the HMI panel while having good functionality, is laid out such that its operation is somewhat less intuitive than it might otherwise have been. The built in oscillography enabled a record to be made of the baseline tests for future reference.

Where future testing maybe required to comply with NERC (North American Electric Reliability Council), future regulations, internal testing capability within the digital controller, such as oscillography and sequence of events recording will help position the mill to performed any future testing as may be required by NERC at minimum cost.

In summary, the experience was a very satisfactory and rewarding one with both the engineering consultant's and the manufacturer's representatives performing as expected to make the job of retrofitting the excitation system on an almost forty year old generator a lot less daunting than it might have otherwise been.

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