Digital Front Ends Offer New Life for Aging Static Exciter Systems on Hydro Turbine Generators

Gene Asbury, Senior Application Specialist, Basler Electric Company, Highland, IL USA

Abstract

Many static excitation systems were installed from the early 1980's and into the 1990's to replace the aging rotating exciters for hydro generating plants in North America.

The Westinghouse MGR and the General Electric Potential Busfed systems were two of the more common analog static exciter systems for field current ratings up to 1000Adc. Today, even some of newer installed and early digital exciters are approaching 25 years of age. Some parts may be available now, but with the passing of time, the chance will increase that the control components of the older excitation systems will no longer be available due to obsolescence.

The logical upgrade for the excitation system is to replace the entire system with a new AVR/Static excitation system. Since the proposal costs may be outside budget limitations and many power stage components still could be in excellent shape, it may be beneficial to consider an alternative upgrade for the excitation systems.

This paper will discuss the application and advantages of retrofitting the excitation system to replace the analog front end controls with a state-of-the-art digital controller, firing circuits, power supplies, field ground detector, and other components (depending on the application), while maintaining the original excitation power bridge and Power Potential Transformer. The advantages of this approach are lower cost, less complexity, an integrated power system stabilizer (if required), and software tools that decrease commissioning time, power system stabilizer tuning and NERC testing.

Introduction

In the 1980s and 1990s, it was common for many power plants, including hydroelectric, steam, and combustion plants, to replace their dc rotating exciters with analog static exciters. There are many reasons plant owners invested in static exciter system upgrades. Several major reasons are listed below.

1. Reduces mechanical issues such as commutator and field breaker wear
2. Provides improved transient response
3. Reduces vibration issues
4. Reduces parts obsolescence issues for the electromechanical voltage regulator and associated devices
5. Increases the efficiency of the system [1]

Static exciters came in different styles, but the main difference was the power stage. Some had six-SCR power bridges and others had three-SCR/diode power bridges with no negative forcing.

The Westinghouse MGR (Medium Generator Regulator), shown in Figure 1, was widely used at hydroelectric plants in North America on turbine generators of various sizes. The MGR may be used as a voltage regulator by working into the field of a rotating exciter or as static exciter working in to the generator field. An MGR controls a thyristor bridge ranging from 20 Adc to 1,000 Adc. If more field current was needed, parallel bridges were provided with the use of reactors for current sharing.

Figure 1 - Westinghouse MGR

Hybrid systems included the GE Bus Fed (Figure 2) and Basler SSE (Figure 3).

Figure 2 - GE Bus Fed Controller (SSE)

Figure 3 - Basler Static Shunt Exciter

<u>The Analog Exciter</u>

There are many manufacturers' analog excitation systems at hydroelectric plants in North America, including OEM excitation systems. In most of these systems, the analog control section may be upgraded to a state-of-the-art digital system while maintaining the power control section. Today, first generation digital excitation systems are being upgraded because of parts obsolescence and support issues. This section focuses on upgrading the Westinghouse MGR, but a good portion can be used for upgrading other manufacturers' models as well.

The Westinghouse MGR simplex unit is illustrated in Figure 4. There are two cubicles: the left side is the Power Cubicle and the right side is the Logic Cubicle. Each cubicle is divided into separate panels. The following is a brief description of each panel.

Power Cubicle

DC Panel - This panel houses the field flashing circuits, the field surge protection, and the shaft voltage protection. The 125 Vdc control power is brought to this panel.

AC Panel - The ac field disconnect is the main component of the ac panel. Also included in this panel are the ac surge protection, associated control relays, and the control power transformer.

Power Converter Panel - This panel contains the power bridge and the associated firing circuits, including fuses, snubber circuits, and pulse transformers. Depending on the application and the size of the generator, the bridge could be a semi-converting bridge or a full-converting bridge.

Logic Cubicle

Electronic Adjuster Panel - Electronic adjusters are mounted at the top of the Logic Cubicle. With all options, the MGR system has three adjusters; one for automatic control, one for manual control, and one for var/power factor control.

Logic Circuit Panel - The logic circuit panel houses the main printed circuit card modules, relays, and internal logic power supply. The three modules on this panel are the voltage regulation circuits, limiter circuits, and the protection circuits.

Voltage Regulation Circuits - Voltage regulation circuits include the basic voltage regulator and reactive current compensation circuit. If specified, this board also includes a var/power factor regulation circuit.

Limiter Circuits - This circuit contains the maximum excitation limiter, minimum excitation limiter, instantaneous current limiter, and volts/hertz limiter. Independent auxiliary signals are provided to move the excitation into the operating capabilities of the generator.

Protection Circuits - This is an optional circuit that provides overexcitation protection, volts/hertz protection, and loss of field protection.

Field Ground Detector - The field ground detector, when required, provides protection against field ground faults. [2]

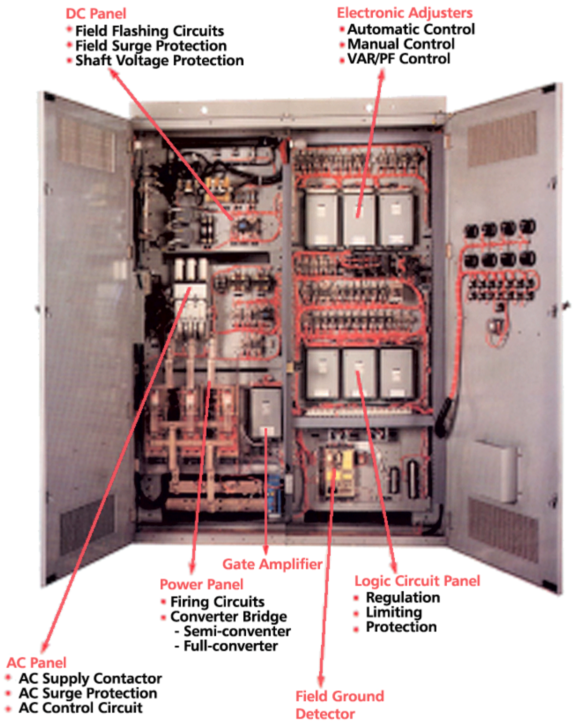


Figure 4 - Internal Components of an MGR Exciter

The Conversion to Digital

There are several factors, listed below, that tend to initiate an upgrade of aging analog excitation systems to new digital excitation systems.

1. Parts availability and obsolescence
2. Model no longer supported by the manufacturer
3. Data recording and software tools needed for periodic response testing per requirements by NERC

A complete replacement of an analog static excitation system can be expensive; thus, reviewing all the options is necessary. If the power plant owner has determined that an upgrade is needed but budget restraints do not allow the necessary funding, a front end solution may be the only way to obtain the proper upgrade. Before a front end solution is proposed, the following questions should be answered.

Question: *Is the existing bridge in good shape?* See Figure 5.
An inspection of the bridge is required to be sure it is in good working condition.

Figure 5 - MGR Rectifier Bridge

Question: *What is the manufacturer's part number for the SCRs used in the rectifier bridge?*
This information is needed to determine the required gate voltage (Vgt) and gate current (Igt) to ensure correct firing by the new firing circuit and gate amplifier circuit.

Question: *What type of bridge is in the static exciter (full-converting or semi-converting)? Is a full-converting bridge required?*
Although not required by regulations, the system operator may require a negative forcing system to improve the transient response of the system.

Question: *What are the existing Power Potential Transformer (PPT) parameters?*
This information is needed to ensure that the PPT is adequate for the application and meets any new requirements applicable to the North American Electric Reliability Corporation (NERC) region in which the machine is located (e.g. increased ceiling levels). See Figure 6 for an example of a PPT nameplate and the information needed.

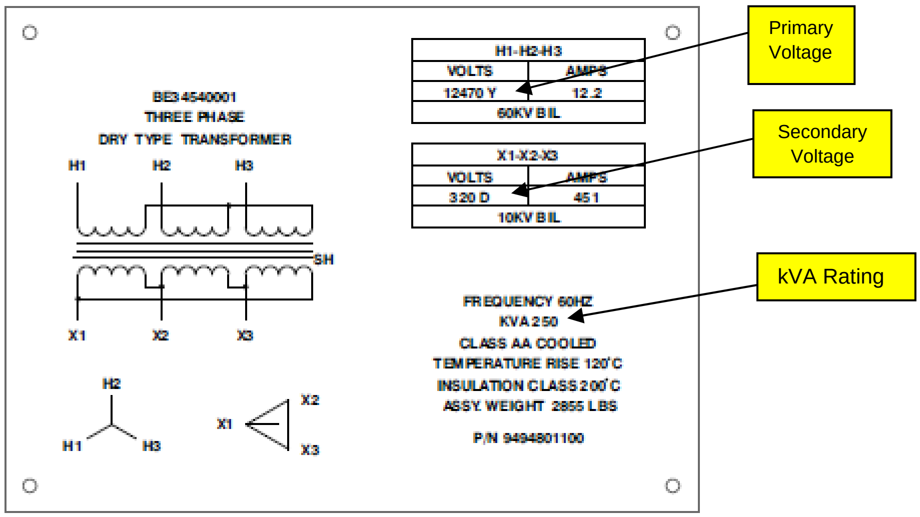


Figure 6 - Example of a Power Potential Transformer Nameplate

Question: *Is there enough space in the existing cabinet to house the new front end panels?*
This is not an issue with analog static exciters, but with first generation digital exciters, there could be an issue. An inspection and measurements of the existing cubicle are required.

Question: *Can the field flash circuitry and ac disconnect be reused?*
These are components that can be replaced with the new front end upgrade. This is dictated by the equipment owner. An inspection of the components is necessary.

After it is determined that a front end conversion is applicable, the design team engineers the required panels based on the necessary equipment and options. Figure 7 shows a three-panel system that comprises a front end solution for an existing analog exciter. The left panel houses the main controller, bridge control circuit, isolation transducer, I/O circuits, and other associated components. The panel in the middle houses more I/O circuits, power supplies, control relays, and other associated components. The right panel is only needed when replacing a field ground detection relay (64F). Another panel, not shown in Figure 7, may be used to house additional bridge control circuitry, if the analog exciter utilizes multiple bridges.

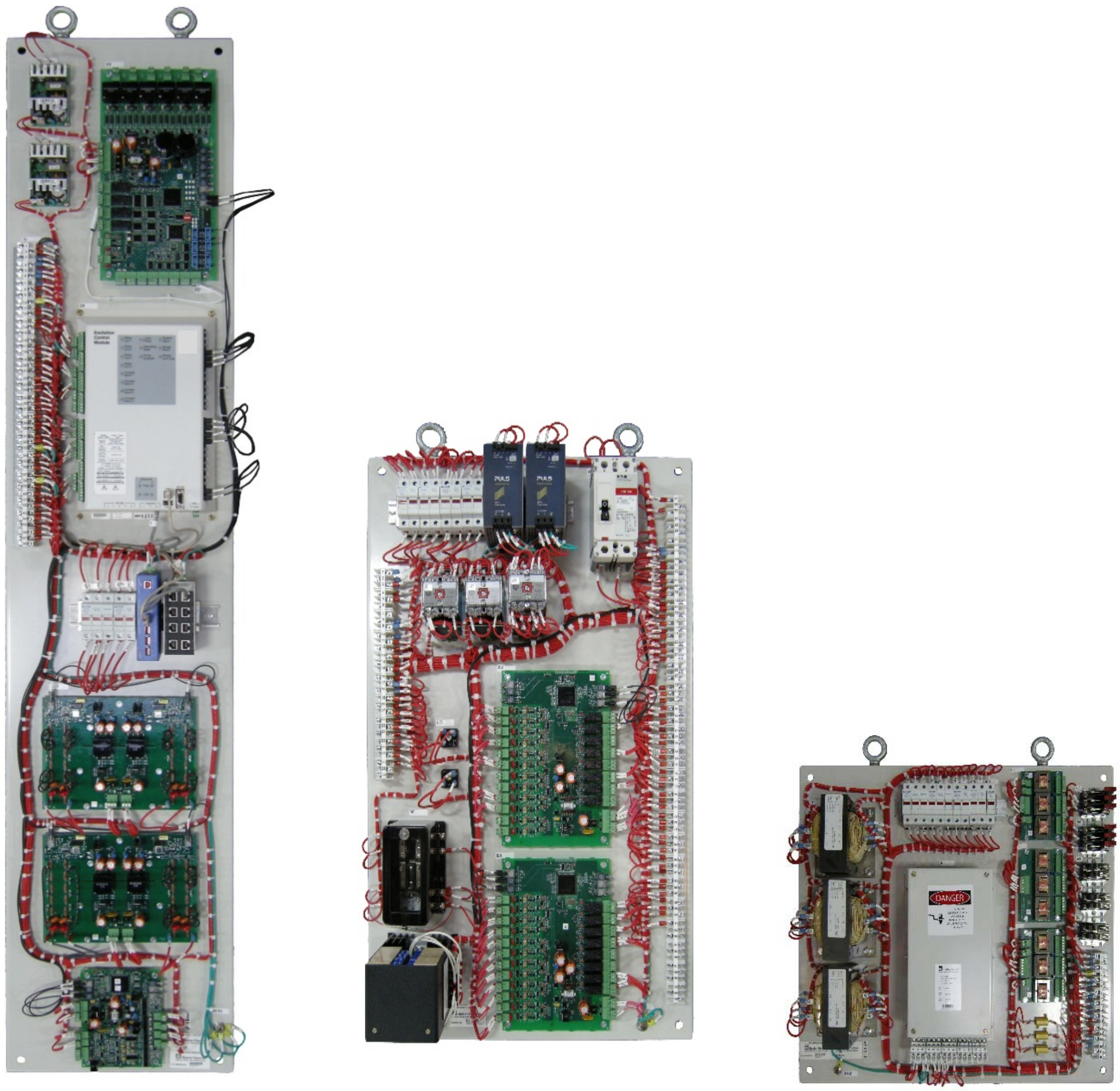


Figure 7 - Digital Front End Panels to Replace Analog Circuitry on an Analog Exciter

On simplex MGR static exciters, these three panels replace the electronic adjuster panel, the logic circuit panel, and the field ground detector panel. Also, the firing circuit and the gate amplifier circuits can be removed from the power cubicle.

The process of designing and manufacturing a front end excitation kit is identical to the process of designing and manufacturing a complete excitation system. The following list outlines the basic steps taken from the time a front end excitation kit order is received to the completion of testing.

1. Purchase order is placed and engineering specification is developed.
2. Engineering approval drawings are developed and submitted to the owner/customer.
3. After the owner/customer has approved the drawing, the final engineering work is completed and the project is released to manufacturing.
4. The modules and circuit boards are individually tested before assembly on the panels.
5. Once the panels are assembled, they are sent to the test cell. They are wired together and connected to an external bridge. A complete functional test is performed on the system.
6. If required, the owner/customer visits the manufacturer's factory to witness-test the front end excitation kit.

Figure 8 illustrates the front end excitation kit in the existing cubicle of the original exciter. The three panels easily fit inside the existing cubicle. A 12-inch HMI touch screen is installed on the front door of the cubicle. See Figure 9.

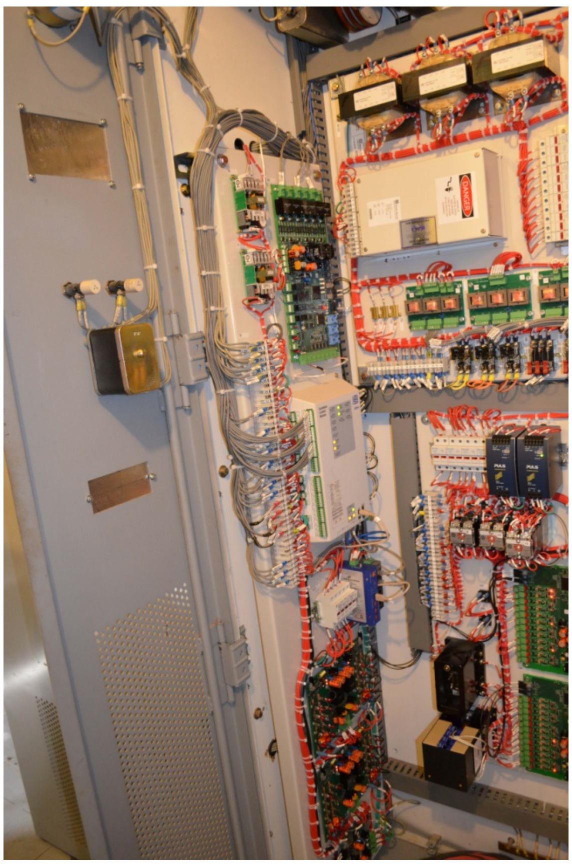


Figure 8 - Analog Exciter Converted into a Digital Exciter

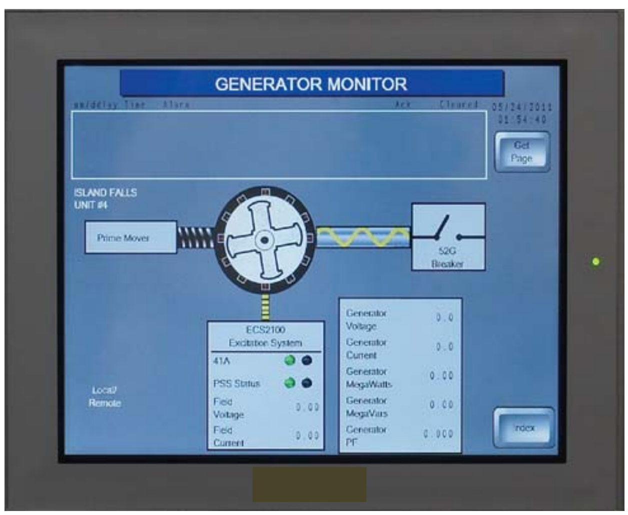


Figure 9 - HMI Touch Screen Display

Advantages and Features of a Digital Exciter

Digital excitation systems eliminate concerns associated with aging analog excitation systems. A new digital exciter provides many added features, several of which are listed below.

- Better regulation accuracy (up to 0.1% from no load to full load)
- Multiple pre-position set points for each mode of operation (initiated by user-defined logic)
- Reactive differential compensation (cross current) via communication link
- Field Voltage Regulation (FVR) operation mode is a manual control mode designed to perform specific tests to validate models for load rejection and capture generator reactance. [3]

NERC VAR-002-1a and Associated Protection

A digital excitation system allows the user to more easily meet new requirements set forth by NERC. One such requirement is described in standard VAR-002-1a, below.

> The Generator Operator shall operate each generator connected to the interconnected transmission system in the automatic voltage control mode (automatic voltage regulator in service and controlling voltage) unless the Generator Operator has notified the Transmission Operator. [4]

High end digital systems incorporate a feature that is common in the protective relay world called 60FL or Voltage Balance Fuse Loss, see Figure 10. When an excitation system loses a leg of its voltage sensing circuit, the exciter attempts to turn full on. Most digital exciters monitor the balance of the sensing circuit and initiate a transfer to Field Current Regulation (FCR or Manual mode) if an unbalance is detected beyond the settable range. A severe transient on the grid can emulate a “loss of sensing” condition and initiate a transfer to FCR mode. This transfer mandates a call to the system operator within 30 minutes, based on the requirements of VAR-002-1a. To avoid these nuisance transfers, the 60FL element monitors the positive sequence and negative sequence voltage and currents, and the modern digital AVR controller determines if the event is a true loss of sensing condition or a transient on the system. This feature allows a transfer to manual mode only when there is a true loss of sensing condition.

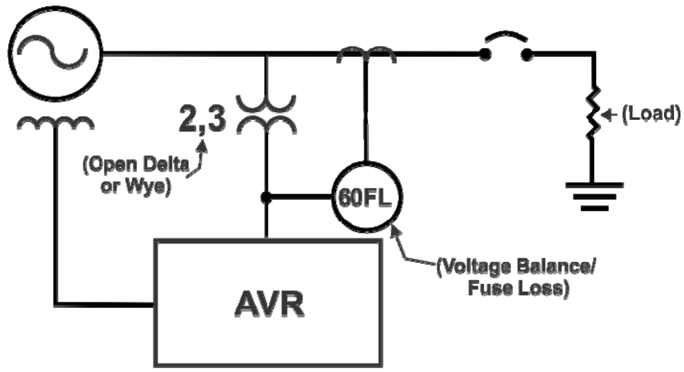


Figure 10 - Voltage Balance - Fuse Loss (60FL) [5]

Other protection elements that are commonly offered in a digital excitation system are:

- Field Overcurrent
- Field Overvoltage
- Field Ground Protection
- Field Temperature Protection
- Generator Overvoltage
- Generator Undervoltage
- Loss of Excitation
- Volts per Hertz Protection
- Exciter Diode Protection (brushless exciter applications)

The protection elements can be displayed as an alarm or enabled as an output. The output arrangement is set by programmable logic software. [3].

Power System Stabilizer

Depending on which NERC region the generator is located in or as a directive from the Transmission Operator, a PSS may be required. In most applications, a PSS2B style, integral of accelerating power, is required in North America. Figure 11 represents the model for type PSS2B dual input PSS.

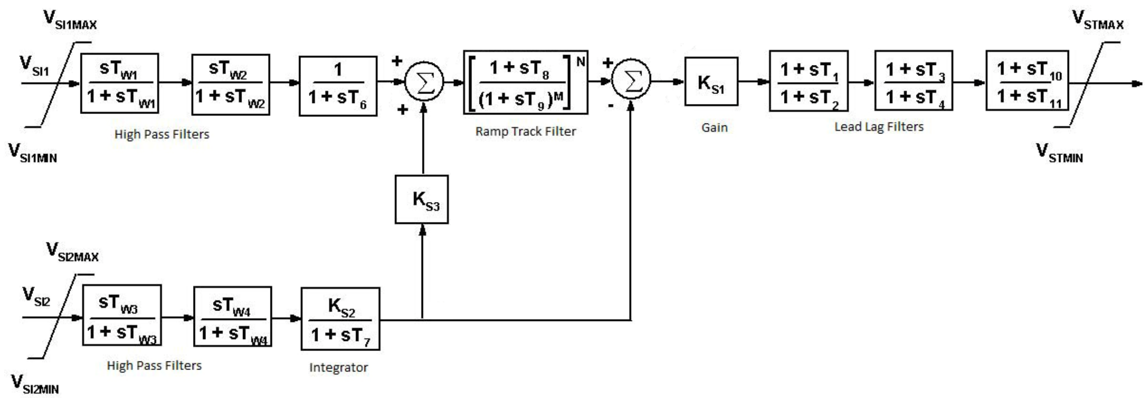


Figure 11 - Type PSS2B Dual Input PSS [6]

If a PSS is required, this feature is integrated into the main controller of the digital exciter. When a PSS is utilized, the excitation system is tuned to be very aggressive in response to terminal voltage deviation to improve the transient stability of the system for the first rotor swing. As the transient stability is enhanced, the natural damping in the system is restored by the PSS [7]. Another valuable feature of the digital exciter is a set of primary and secondary gain settings. These settings allow the user to tune the exciter to be very aggressive when the PSS is active and slow the response when the PSS is inactive.

To assist in the commissioning of the PSS, most modern digital controllers' software is equipped with the ability to perform the frequency response test with immediate bode plot results. See Figure 12.

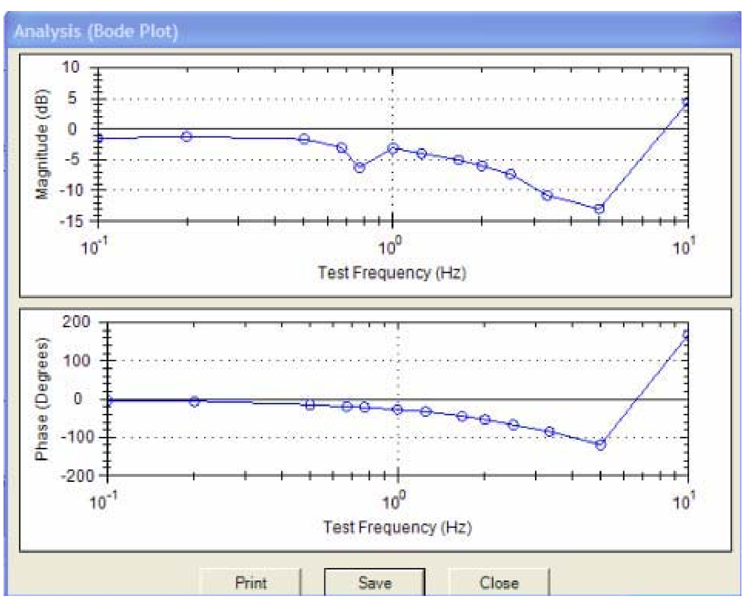


Figure 12 - Frequency Response Using a Built-in Dynamic Analyzer [7]

Limiters

Analog excitation systems have several maximum and minimum limiters along with instantaneous and volts/Hz limiters. Limiters used in modern digital excitation controllers are listed below.

- **Minimum Excitation Limiter -** This function operates in the same manner as traditional analog systems in that the limiter curve is based upon assuming it is a steady-state stability limit.
- **Underexcitation Limiter -** The underexcitation limiter is identical to the minimum excitation limiter. However, it can recalibrate the limit curve based on hydrogen gas pressure or stator temperature.
- **Overexcitation Limiter –** An overexcitation limiter limits the duration of excessive field current applied to the machine's field.
- **Volts per Hertz Limiter –** This function limits excessive volts per hertz operating conditions that could over flux the generator and connected transformers.
- **Overvoltage Limiter –** The overvoltage limiter protects the generator from sustained, high levels of terminal voltage. This can occur during full load rejection on hydro units.
- **Undervoltage Limiter –** An undervoltage limiter prevents the generator voltage from reaching an undervoltage condition. Low terminal voltage can occur with a failure of the excitation system.
- **Minimum Field Excitation Limiter -** Where the minimum excitation limiter and underexcitation limiter sense reactive power on the generator, the minimum field excitation limiter monitors the field current and maintains it at a user-adjustable level.
- **Instantaneous Overcurrent Limiter –** This limiter is similar to the overexcitation limiter, but with no intentional time delay.
- **Var Limiter –** A var limiter prevents a high level of lagging vars that can be the result of a failure within the excitation system.
- **Stator Current Limiter –** This function monitors the level of stator current and limits it to prevent stator overheating. It only affects the reactive portion of the generator line current.
- **Soft Start –** Soft start limits the rate at which the generator terminal voltage builds towards the set point to prevent overshoot.

It is easy to see that modern digital excitation systems provide more flexibility and control when regulating hydro turbine generators.

With the advanced software tools for modern digital exciters, setting the limiters and coordinating them with protection becomes a more precise exercise. See Figure 13.

This feature is now more valuable since the implementation of NERC Standard PRC-019-1. The purpose of this standard is to verify coordination of generating units' or synchronous condensers' voltage regulation controls, limiting functions, equipment capabilities, and protection system settings [8].

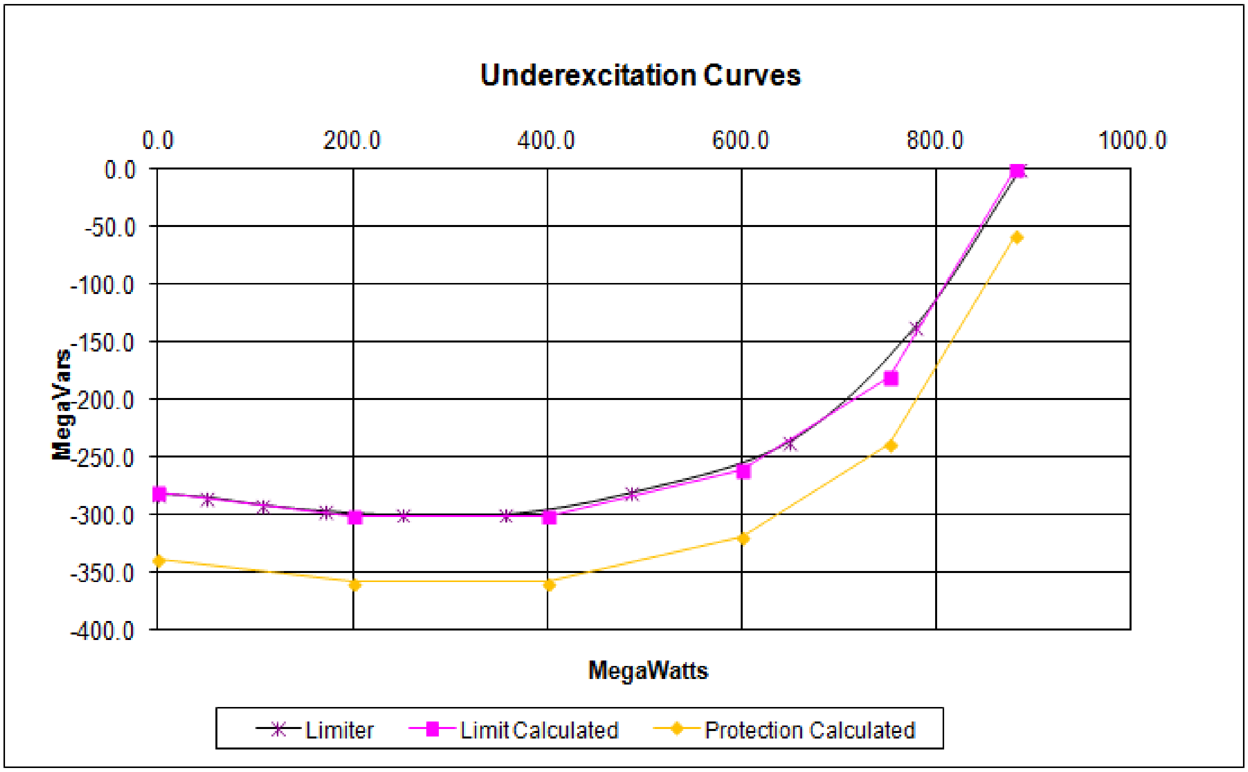
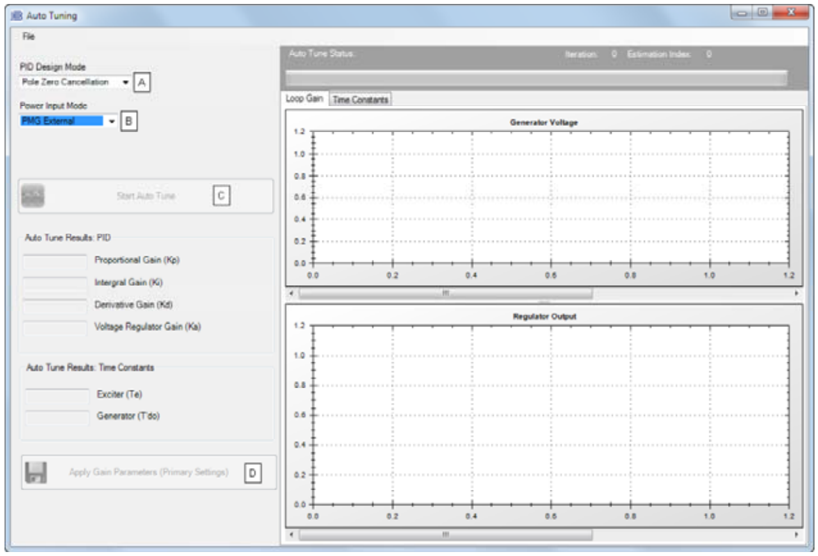


Figure 13 - Underexcitation Limiter Programmable Feature

Auto Tuning

With the requirement to run the generator in AVR control, it is important to have an optimally-tuned AVR system. Because most modern digital controllers utilize the proportional, integral, and derivative (PID) control for stabilization, knowing all the machine parameters (field time constants) is critical to properly tune the excitation system. Not having this information causes a considerable time delay and higher cost due to increased fuel usage for commissioning the AVR system [9] [10].

Modern digital controllers are equipped with an auto tuning feature that allows the user to perform a test via the controller software (Figure 14) at rated speed and with the generator breaker open.



A - *PID Design Mode:* Set to either Pole Zero Cancellation or Pole Placement.
B - *Power Input Mode:* Set to either PMG External or Shunt.
C - *Start Auto Tune Button:* Begins the auto tuning process.
D - *Save PID Gains Button:* Saves the calculated PID gains.

Figure 14- Auto Tuning Initiation Screen

When the test is complete, the AVR system is tuned. Fine tuning can be performed during the required step test. The Auto Tuning feature saves valuable time when commissioning the excitation system.

Software Tools

Two software tools have been discussed in this publication thus far. The first one provides the ability to perform a frequency response test while commissioning the PSS. The other software tool is the auto tuning feature, which allows the user to quickly obtain gain settings and time constant values. Another very valuable software tool is Real Time Monitoring, see Figure 15. It allows the user or the Commissioning Engineer to monitor up to six (6) parameters while doing a step response test. This saves time during the commissioning process and for periodic NERC testing.

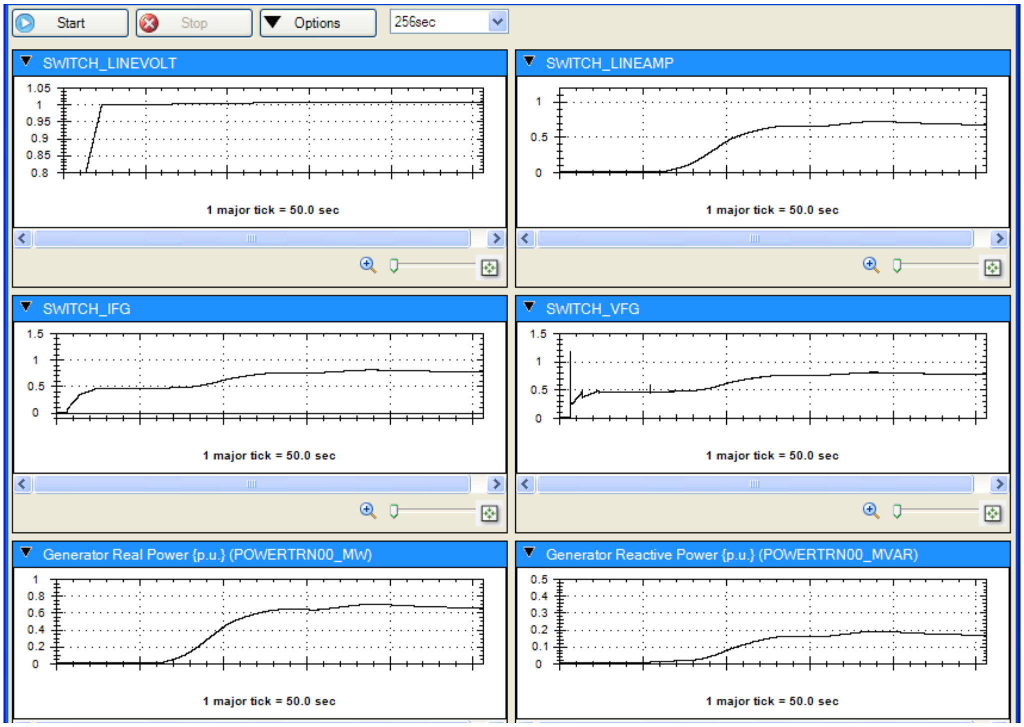


Figure 15 - Six-Channel Real Time Monitoring

The digital front end solution provides diagnostic tools that assist in troubleshooting. These diagnostic tools include event recording, sequence of events reports, and, in some cases, a trending report that provides an extended look at the generating unit's performance.

The event recording tool stores multiple events in memory. An event can be triggered by logic, a parameter exceeding a certain level, or a step response test. Figure 16 shows an example of an event recording that samples data in as fast as 1 millisecond. This data can be viewed using the viewer associated with the interface software package, a Comtrade format viewer, or using ASCII log data to generate the response in a spreadsheet.

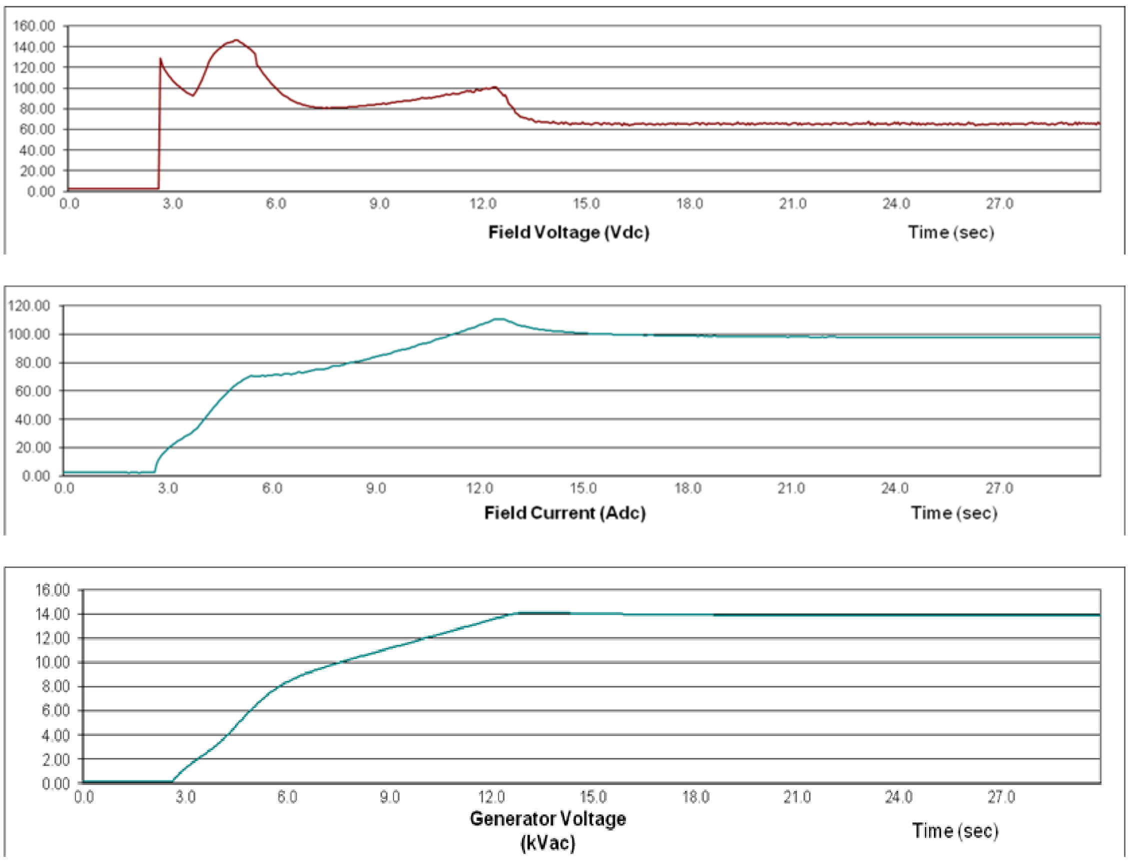


Figure 16 - Single Event Recording

Sequence of events data is a powerful troubleshooting tool. It provides the user with a detailed description of how the exciter has performed. It records every action the exciter executes and records it with a time and date stamp. Time may be synchronized via an IRIG-B input or through Network Time Protocol (NTP). The Sequence of events data is downloaded in tabular format and is illustrated in Figure 17.

(Address:2 Level:5) - 10.0.1.250 - Alarm History

History | Device Log | Tools

Time	Description	State
12/29/2011 11:22:45.552 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Cleared
12/29/2011 11:22:45.554 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Event
12/29/2011 11:22:45.555 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Cleared
12/29/2011 11:26:18.005 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Event
12/29/2011 11:26:35.135 AM	LT00 F1 alarm: Phase Locked Loop Not Locked	Alarm
12/29/2011 11:26:35.135 AM	PT00 F1 alarm	Alarm
12/29/2011 11:26:35.188 AM	LT00 F1 alarm: Phase Locked Loop Not Locked	Cleared
12/29/2011 11:26:35.188 AM	PT00 F1 alarm	Cleared
12/29/2011 11:26:36.097 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Cleared
12/29/2011 11:26:36.098 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Event
12/29/2011 11:26:36.099 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Cleared
12/29/2011 11:26:36.100 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Event
12/29/2011 11:26:36.101 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Cleared
12/29/2011 11:26:36.102 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Event
12/29/2011 11:26:36.103 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Cleared
12/29/2011 11:28:31.362 AM	AUTOMAN_AUTO_EN - True= Regulator in Auto	Event
12/29/2011 11:28:48.491 AM	LT00 F1 alarm: Phase Locked Loop Not Locked	Alarm
12/29/2011 11:28:48.491 AM	PT00 F1 alarm	Alarm
12/29/2011 11:29:13.000 AM	OR40_OUT - True= Generator On-Line	Event
12/29/2011 11:29:13.000 AM	PT00 F1 alarm	Cleared
12/29/2011 11:29:13.001 AM	PT00 F1 alarm	Alarm

Figure 17 - Sequence of Events

Conclusion

There are many analog static exciters at hydro facilities all over the world. To meet agency specific requirements or to prolong the existing excitation system, a front end digital excitation kit may be the best solution. It provides many features that help the user perform required periodic testing. A new digital front end also provides the tools to troubleshoot the system when needed.

This publication focuses mainly on Westinghouse MGR exciters and how to retrofit them with a digital front end. As mentioned before, the same techniques can be used on other manufacturers' analog exciters.

Reference

[1] "16 Reasons to Replace Rotating Exciters with Digital Static Exciters". Basler Electric Company. Publication #EX-REP. (March 2002).

[2] "MGR Excitation System for generators that require up to 150kW of excitation". Westinghouse Electric Corporation. Publication #ECE-9107.

[3] Asbury, Gene P. "Modern Digital Controllers Provide Additional Features to Improve Hydro Generators Reliability". Hydrovision, Denver, Colorado. Basler Electric Company. (2013)

[4] NERC Standards VAR-002-1a. Generator Operation for Maintaining Network Voltage Schedules. (August 1, 2007).

[5] Buscher, Dale. "Avoiding loss of voltage sensing runaway for generator excitation systems". *Pulp and Paper Industry Technical Conference (PPIC), Conference Record of 2011 Annual IEEE*, pp.120, 123. (June 19-23, 2011).

[6] IEEE standard 421.5-2005, *IEEE Recommended Practice for Excitation System Models for Power System Stability Study* (2005).

[7] Kral, David S., and Richard C. Schaefer. "Easing NERC Testing with New Digital Excitation Systems." Basler Electric. (August 2008).

[8] N.E.R.C. Standards PRC-019-1. Coordination of Generating unit or Plant Capabilities, Voltage Regulating Controls, and Protection

[9] Kim, Kiyong; Rao, P.; Burnworth, J. "Self-Tuning of the PID Controller for a Digital Excitation Control System," *Industry Applications Society Annual Meeting*, 2009. IEEE-IAS. pp.1, 8, 4-8 Basler Electric Company (October 2009).

[10] Schaefer, Richard C.; Kiyong Kim, "Digital Excitation System Provides Enhanced Tuning Over Analog Systems". Basler Electric Company.

Biography

Gene Asbury (IEEE member), has been a Senior Application Specialist for Basler Electric Company, in Highland IL, since 2006. He has performed in various capacities since he started with Basler Electric in 1987: Quality Control Supervisor, Technical Sales Specialist, Project Coordinator, Proposal Engineer, and Application Specialist for Excitation Systems. Gene attended Southwestern Illinois College and received degrees in Industrial Technology and Communication Electronics.

Basler Electric®
www.basler.com

Highland, Illinois USA
Tel: +1 618.654.2341
Fax: +1 618.654.2351
email: info@basler.com

Suzhou, P.R. China
Tel: +86 512.8227.2888
Fax: +86 512.8227.2887
email: chinainfo@basler.com