Specifying Excitation Systems for Procurement

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Abstract: *With today's microprocessor technology, digital excitation systems have become very versatile compared to their analog voltage regulator predecessors. Full function digital excitation systems come equipped with various operating modes necessary to control terminal voltage on the synchronous machine. In addition, a full complement of excitation limiters is provided to ensure control of the synchronous machine over a wide range of operating conditions.*

When specifying new excitation systems, it is important to consider all of the various factors that can affect the successful purchase of the new equipment. These include but are not limited to environment, location of the excitation system, applicable specifications, agency requirements, performance, and ratings.

This paper discusses considerations involved in specifying the excitation system for a project.

I. Specifying the Excitation System Rating, Static Exciter Systems

Perhaps the single most important concern in specifying the new voltage regulator is properly identifying the application. Is the new excitation system intended for the main field of the generator or the shunt field of the rotating exciter? See Figure 1.

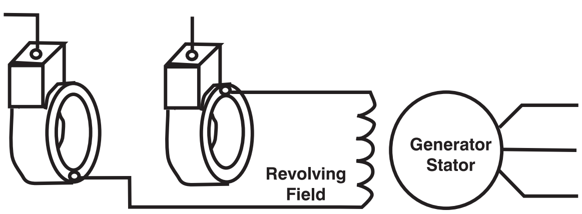

Figure 1. Slip-Ring Generator

Depending on the circumstances, sizing the excitation system can be derived from the generator nameplate as shown in Figure 2 or, looking at worse case and sizing the excitation system requirements for 115% the rated kVA at 105% rated voltage of the generator. Where the generator has been rewound or is anticipated to be rewound for a higher machine rating, it is important to consider the additional power requirements of the generator main field.

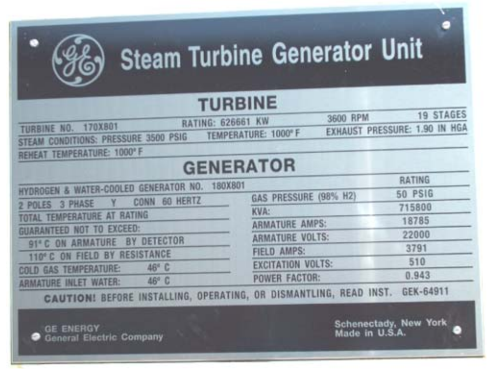

Figure 2. Generator Nameplate

Field Forcing Concerns

For short time disturbance response, an overload rating is applied to the excitation system. Field forcing provides the ability to deliver higher than normal operating capacity to the field for short periods of time, typically a total of 30 seconds. Field forcing represents the percent of maximum ceiling voltage that can be applied to the field from rated full load field. Depending upon regional requirements, the magnitude can vary from 150% to 200% of full load, or even higher if there are special requirements to consider. "Field forcing" often is expressed in terms of the Response Ratio, as referenced in IEEE 421.2. [1]

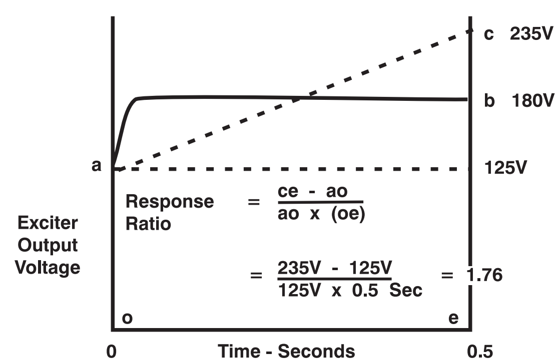

Figure 3. Excitation System Voltage Response

To determine the response ratio, the exciter is brought to its full rated voltage, then terminal voltage is suddenly dropped by 20%, and the response is recorded for the first 0.5 seconds. A straight line, a-c, is drawn and calculated to be equal to the equivalent to a-b. The formula then is calculated as shown, with the answer being 1.76, as shown in Figure 3. Obviously, by increasing the ceiling voltage to be greater, the response ratio becomes larger. [6]

The time duration required for maximum field forcing is a very short period, reaching the maximum value and holding for perhaps 3 seconds, then following an inverse time curve to approximately 110% of the full rated over a duration of approximately 30 seconds. ANSI C50.13 offers guidelines that show the permissible short time overload current plotted against time for cylindrical rotor machines. [7]

The Power Potential Transformer

Another element of the excitation system is the power potential transformer that provides the appropriate voltage for the rectifier bridge. See example, Figure 4. The manufacturer specifies the power potential transformer kVA once the field forcing requirements have been defined. Most power potential transformers are convection cooled, dry type and designed with anticipated harmonic content, but other considerations may include higher than normal BIL (Basic Impulse Level) ratings that may be above the normal manufacturer rating, special impregnation such as vacuum impregnation. Epoxy cast or resin core coils may be specified at times, depending upon the location of the power transformer. Each special requirement adds cost to the excitation system.

Figure 4. Excitation Power Potential Transformer

II. Bridge Rectifier Selection

The bridge rectifier used to convert ac to dc can be one of two types: half wave (3 SCR and 3 diode, see Figure 5A) or full wave bridge (6 SCR). Twenty years ago, the half wave bridge was very popular for main field applications, but today most new excitation systems require two (2) quadrant, 6 SCR bridges that provide for both positive and negative field forcing for optimum performance and faster generator voltage decay at shutdown. See Figure 5B. [8]

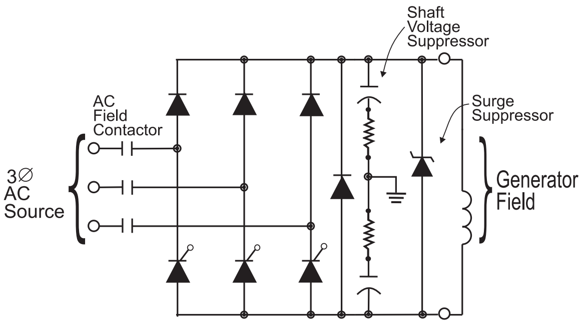

Figure 5A. 3 SCR Half Wave Bridge

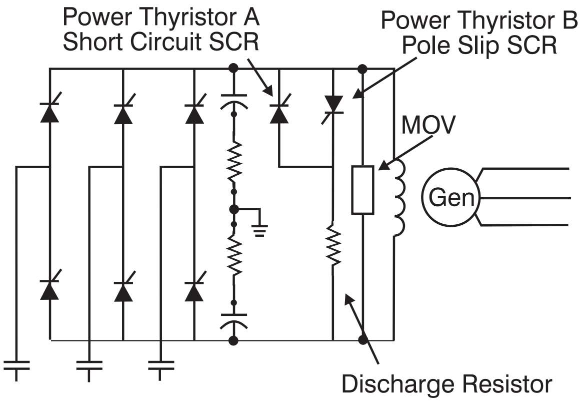

Figure 5B. 6 SCR Bridge with Crowbar Fast De-excitation Circuit

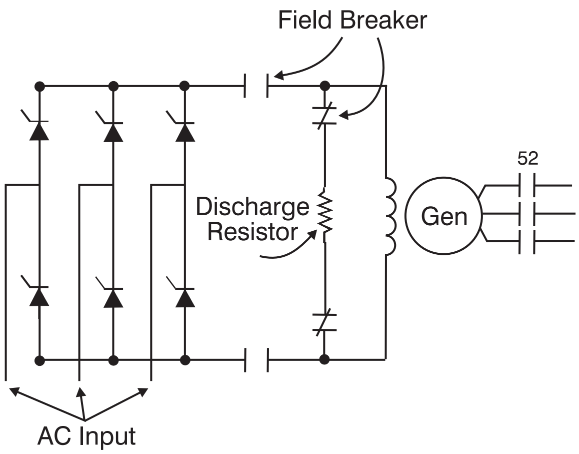

Figure 6. Full-Inverting Exciter System
with Field Breaker

Where the dc field breaker (Figure 6) has been the standard for dc machines for years, due to age and cost and general mechanical concern, the dc breaker is being replaced for an ac field breaker at the ac input to the rectifier bridge. The discharge contacts are now replaced for a couple of SCRs connected in antiparallel, that is, connected in series with a discharge resistor to dissipate the field energy at shutdown. Figure 4B illustrates the crowbar circuit with SCRs for controlling the insertion of the field discharge resistor.

III. Rotating Exciter Voltage Regulator Applications

For rotating exciters, the excitation field requirements change quite dramatically. Instead of a current range of a few hundred to thousands of Amps for the main field, the voltage regulator field requirements range from 10 Amps to a couple hundred Amps for very large synchronous rotating exciter machines. For these systems, the voltage regulator works directly into the exciter shunt field and eliminates various types of pilot exciters, including the Amplidyne and the multiple field Rototrol exciters. See Figure 7. When sizing for the exciter field requirements, it is very important to obtain the exciter shunt field requirements for sizing the new excitation system. Unlike the generator nameplate provided on the main field excitation systems, the rotating exciter field information is not obvious. Often, measurements are necessary to obtain the operating field current of the exciter shunt field and voltage at full load to be sure of the rating required for the new excitation systems.

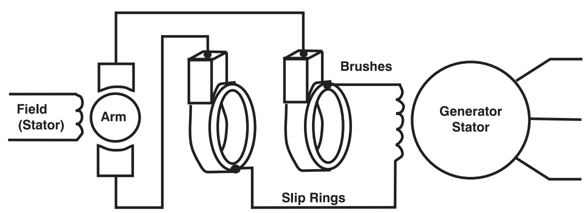

Figure 7. Rotary-Excited Brush Type Generator

Bridge Selection for the Voltage Regulator

Since the voltage regulator drives the exciter field, the type of bridge utilized is very important to achieve the best performance results. In this case, the 6 SCR bridge needs to be utilized. For exciter field applications, the magnetic flux needs to decay as quickly as possible in order that the generator flux can be drained quickly from the main field. This is particularly important on machines that have large machine exciter and main field time constants or that require power system stabilizers to optimize machine performance to improve transient stability recovery. See Figure 5B.

IV. Equipment Features

Today, the excitation system comes equipped with a full complement of features regardless if it is a voltage regulator working into the exciter field or the generator main field. The features are integrated into a single controller with microprocessor architecture. Often, the operating software associated with the new excitation system allows for enabling and disabling of features important to the application. Table 1 identifies functions common to a new excitation system. In developing the technical specification, all features designed for the application should be specified to prevent misinterpretations of the equipment needs.

Table 1. Voltage Regulator Features

Feature	Description
OPERATING MODES	
Voltage Regulation	Better than 0.20% accuracy 0-120% control range
Var/Power Factor Control	Maintains Constant Power Factor or Constant Vars
Automatic nulling	Between operating modes and/or redundant digital controllers for bumpless transfer
Voltage Softstart	Builds up terminal voltage slowly, based on programmed time intervals
Volts/Hertz Ratio Limiter	Maintains Volts/Hertz Ratio to prevent overfluxing of synchronous machine
Minimum Excitation Limiter	Flexible 5 point map on real/reactive power axis or internally-generated UEL curve
Maximum Excitation Limiter	Limits rotor heating due to excessively long periods of field overcurrent
Stator Current Limiting	Limits Stator Current after short time delay
Dual PID Setting Groups	Allows for programmed changes in PID gain settings for use with Power System Stabilizer to optimize voltage response with or without PSS
Autovoltage Matching	Automatically matches generator voltage to bus voltage
2 preposition set points	Programmable for AVR, Manual, Var/PF Controller
Reactive Drop or Line Drop	
Transient Boost	Dynamically stabilizes the rotor after fault conditions
Loss of Voltage Sensing	Transfers to manual control automatically due to loss of voltage sensing at the voltage regulator
Oscillography	600 points, 6 programmable parameters, holds up to 6 records
Sequence of events	127 records
Real Time Monitoring	Chart Recorder for test analysis
Built-in Dynamic Analyzer	Measures frequency response of generator and excitation system
Protection	Field Over Voltage, Generator Over/Under Voltage, Field Overcurrent, Loss of Voltage Sensing, Loss of Field, Volts/Hertz Protection
Field Overvoltage, Generator Over/Under Voltage, Field Over Current, and Loss of Field Protections	Dual set points that are selectable via programmable logic
HMI	Human Machine Interface that displays metering quantities, alarms, and provides control
IRIG-B Time Synchronization stamp	
Generator Field Temperature Monitoring	For use with brush-type or main field excited systems
2 Analog Transducer Outputs	4-20 ma Amp output
Built-in Power System Stabilizer	Optional - Type PSS 2A or selectable Frequency Type
Field Ground Detection	

V. Excitation Power for Rotating Exciters

For many steam or combustion turbine generators with brushless exciters, the voltage regulator system often is powered from a permanent magnet generator. The PMG (see Figure 8) is a self-excited generator that provides reliable three phase power (or sometimes single phase power) at some frequency, typically in the range of 120 to 500 Hertz, depending on the manufacturer. [5] The benefit of the permanent magnet generator is that the output is always constant regardless of degradation in terminal voltage due to fault or machine overload. As an alternative, some excitation systems use station power for the voltage regulator. Here, a 480Vac is commonly used to supply power into the rectifier bridges.

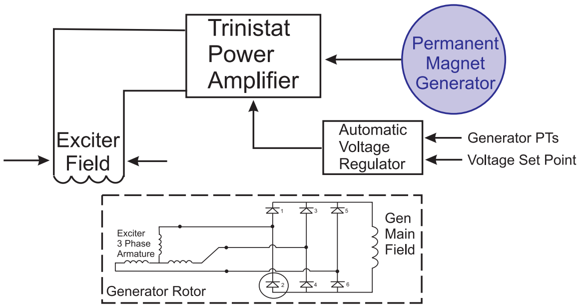

Figure 8. Permanent Magnet Generator

VI. Special Feature Considerations

Power System Stabilizer

Depending on the importance and size of the machine to the system, other features may be included to enhance the uptime reliability of the machine. Since the blackouts that occurred in the Eastern and the Western United States, the use of power system stabilizers has become increasing popular. In the Western United States, the WECC (Western Electric Coordinating Council) requires power system stabilizers on all machines 35 MVA and higher and on all groups of machines in a plant totaling 75 MVA. The power system stabilizer provides damping to power system oscillations that occur after a fault. [9]

Redundant Digital Controllers

For base loaded machines, redundancy usually is specified. The cost of a machine trip caused by an excitation failure can be costly. In the unlikely event it should occur, backup digital controllers will transfer and provide the means for the machine to remain on line. The end user may specify either a redundant full function controller and/or a redundant rectifier bridge for the system. See Figure 9.

The redundant digital controllers are set up for transfer to the backup controller in the event of a malfunction in the primary controller. Transfer can be based on an internal watchdog processor monitor that detects failure in the digital controller, accompanied by internal field overcurrent monitoring as well as independent external field overcurrent monitoring.

The redundant controller is equipped with duplicate features such as voltage regulation, manual control, var/Power Factor control, excitation limiters, and power system stabilizers. Each digital controller automatically tracks the other for a bumpless transfer. Depending on the manufacturer, the digital controller can be either drawout construction for easy on-line replacement or fix mounted.

Figure 9. Cabinet with Redundant Digital Excitation Control Systems

Backup Instrument Transformers

In the past, excitation systems offered an independent manual control as backup to the voltage regulator and a fault transfer in the event of the AVR failure. Now, the manual control is integrated into the digital controller and used only for commissioning and transfer in the event of loss of voltage sensing.

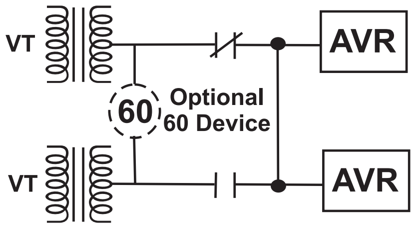

Figure 10. Dual Channel AVR with Dual Instrument Transformers

To avoid transfer to manual control in the event of loss of voltage sensing, it is not uncommon to specify a second set of instrument transformers to be supplied to the voltage regulator. In the event of an instrument PT fuse failure, an automatic transfer to the second set of instrument transformer occurs, which allows the excitation system to remain in voltage regulating mode.

Redundant Bridge

Redundant rectifier bridges for base loaded machines also are common to avoid possible machine trip due to a failed SCR bridge. Depending upon field requirements, the bridges can be sized for 100% redundancy so each bridge is designed to carry the continuous rating of the field or N+1 redundancy where current is divided between multiple bridges and, if one bridge fails, the two remaining bridges will be able to meet the full load requirements. See Figures 11 and 12. Depending upon the manufacturer, the bridges can be either drawout or fixed rack design.

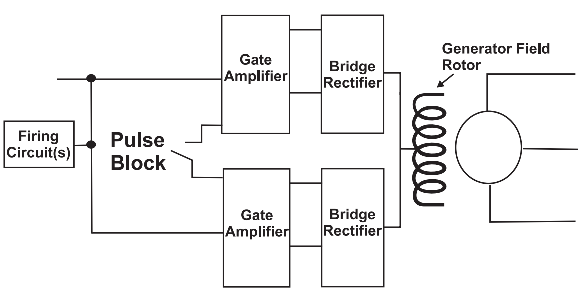

Figure 11. 100% Converter Redundancy

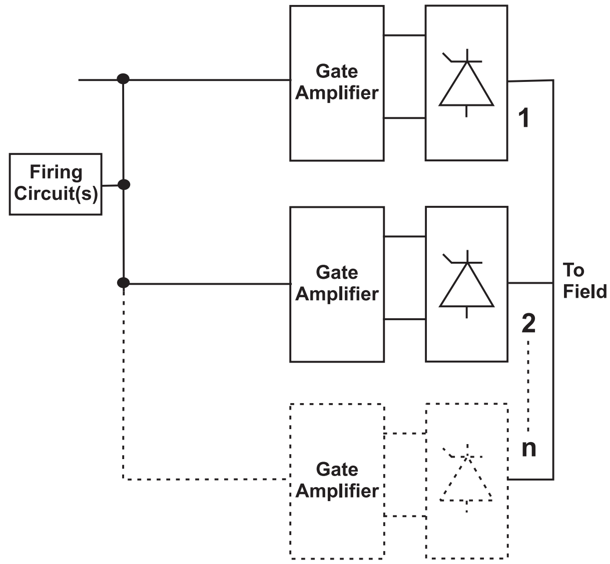

Figure 12. N+1 Converter Redundancy

VII. Environment

It is important to know the issues involved in equipment location. If there is possible dripping water, the cabinet needs to be specified with an overhead extended roof to keep moisture and water from dripping into the cabinet. If water splashing is possible, the cabinet should be equipped with louvers instead of punched holes and the louvers need to be located above the splash area.

Temperature can be a concern, as some power plants will become particularly warm. Although new equipment is fairly tolerant of high temperatures, if the temperature rises above 50°C ambient, long-term life can be affected. Steps can be taken by adding an air conditioner and/or locating the equipment in a controlled environment.

If the equipment is located outdoors near the seacoast, salted air spray can cause rusting and metal decay. The specification needs to call for the equipment to be located in an environmentally controlled room.

Space can become an issue if not considered in the project. The size of the exciter and transformer cabinet must be addressed to make sure there is space for each item, where the termination will be made, and how the conduit will be dropped into the cabinets. Consider how the exciter cabinet doors open. If the exciter cabinet has two doors, having them open from the center can be useful. Specifying lighting and outlets in the cabinet help insure a comfortable working area when commissioning begins or for follow-up maintenance.

Where drawings are available, provide layout drawings as well as an interconnect drawing of the existing system. Note the available power supply voltage control power; e.g. 120 Vac and 125 Vdc are important.

VIII. Exciter Models

Transfer function of the exciter system is important information in order that transmission engineers can properly analyze data against real time performance of the generator and excitation system. It is important to specify this requirement at the time of equipment specifying. See Figure 13. [3, 12]

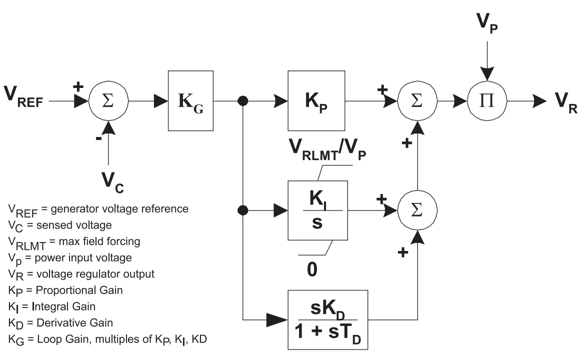

Figure 13. Block Diagram of PID AVR

IX. Turnkey

Today, power plant personnel can be in short supply with changes in personnel structure. Where plant personnel often would have performed the design detail and installed the new excitation system, today's shortage of manpower may prevent this in many cases and outside contractors are used to accomplish the task. The level of involvement may include total turnkey or technical direction. [10]

<u>Defining the Project</u>

To have a successful project, communication between the end user and the vendor is necessary. The following outlines a summary needed by the vendor:

1. Defined schedules.
2. Drawings (system elementaries, connections, and interconnections) of the existing system.
3. Generator design data and curves.
4. Cable and conduit availability
5. Review how the interface is to be developed, from contacts inputs or digitally input from a RS-485 serial communication.
6. Documentation format for the final drawings.
7. Technical training schedule.
8. Technical specification.

<u>Customer Expectations from the Turnkey Contractor</u>

1. System Interconnection Drawings.
2. Electrical Construction Details.
3. Specification of all Installation Materials.
4. Bill of Material to include installation materials, additional interface relays, control switches, indicating lights, meters, etc.
5. Demolition details.
6. Installation details.
7. Interface details.
8. Electrical layout.
9. Grounding details.
10. Cable and conduit schedule.
11. Wire schedule for all modification work.
12. Equipment Interconnection Diagram.

<u>Final Documentation</u>

1. All instruction manuals that apply to all of the equipment.
2. New recommended operational procedures.
3. Elementary and Construction Drawing Package.
4. Software settings for the new excitation system.
5. Operating software for the new excitation system.
6. Spare and Renewal Parts information.

X. Startup and Commissioning

Schedules continuously are being squeezed to maximize power production, and commissioning time for the new equipment is often pushed to a minimum to meet market power demands. Time lost in commissioning represents lost revenue. Hence, the emphasis on testing makes it important to have tools built into the operating software of the new excitation system to speed the effort. See Figure 14. [4]

These commissioning tests will minimally include:

1. Startup and Sequence Logic Checkout
2. Off-line and On-line voltage step responses (See Figure 15)
3. Under Excitation (See Figure 16) and Over Excitation Limiter testing
4. Volt/Hertz Limiter
5. Autotracking verification between operating modes and Digital Controllers
6. Frequency Response Testing
7. Power System Stabilizer Testing

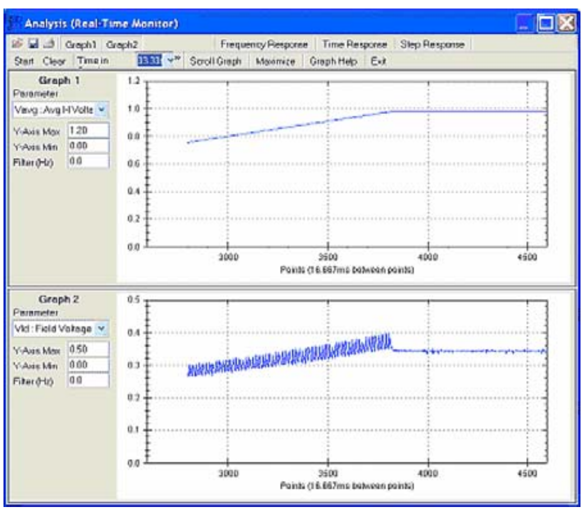

Figure 14. Voltage Buildup in Voltage Regulator Mode at Startup Commissioning

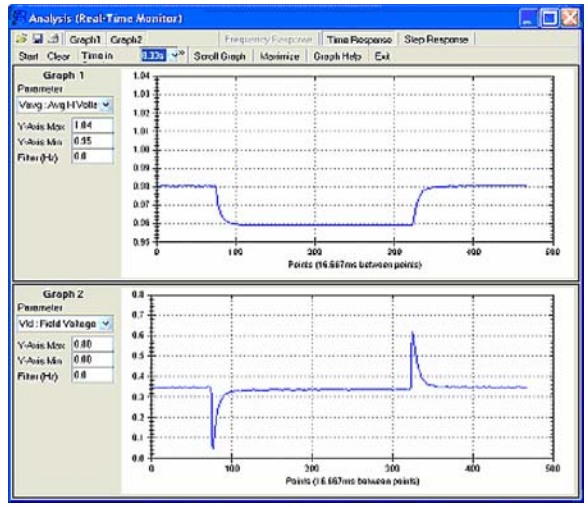

Figure 15. 5% Voltage Step Change in Voltage Regulator Mode

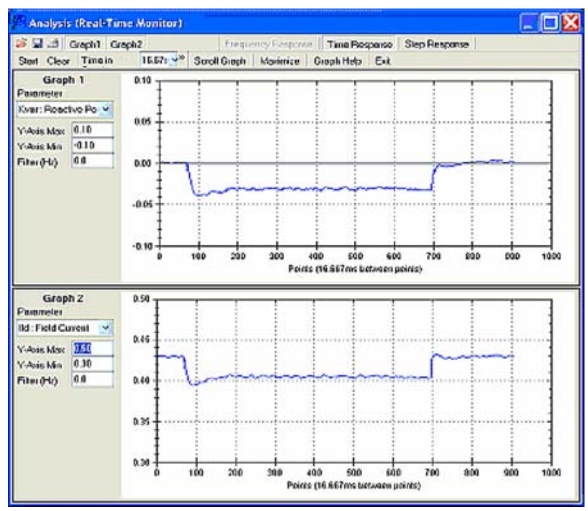

Figure 16. Under Excitation Limit Dynamic Step Test

Figure 14 shows results of the generator voltage buildup during initial commissioning. The top graph illustrates the generator voltage, while the lower graph denotes the accompanied field voltage.

Off-line voltage step responses (illustrated in Fig. 15) are introduced for a 5% voltage step change from the initial set point.

Figure 16 illustrates Underexcitation Limiter stable operation when a large voltage step change has been initiated.

A final report of all of the performed tests should be expected at time of completion of the equipment testing, including oscillography record fields, setting files, and calibration data.

XI. Guide Specifications for Reference

Over the years, IEEE has created a number of technical specifications to help the end user to prepare the purchasing document needed to define the excitation system. These reference specifications include IEEE 421.4 "Guide for the Preparation of Excitation System Specifications" and IEEE 421.2 "Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control System". [1, 2] Where NERC is involved, the WECC requires these tests to be documented and submitted in a report, along with other pertinent data. [11] When a specification is intended to be applied to some portion of the specifying document, it should be referenced at the sentence it is being applied.

Conclusion

When specifying the excitation system, it is important to share all the information that is pertinent to proper selection. Definitions of performance, location, features, and drawing documentation are necessary. The Appendix highlights the questions that should be addressed to help ensure the specification accurately defines the equipment needs.

References

[1] IEEE Std. 421.2-1990, IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems

[2] IEEE Std. 421.4-1990, IEEE Guide for Specification for Excitation Systems

[3] IEEE Std. 421.5-1992, IEEE Recommended Practice for Excitation System Models for Power System Stability Studies.

[4] Brimsek, M., Kim, K., Rao, P., and Schaefer, R.C., "Feature Enhancements in New Digital Excitation Systems Speeds Performance Testing", Presented at Doble Client Conference, April 2006.

[5] Demcko, J., Vachon, T., Stendin, A., Schaefer, R.C., and Ross G., "New Solutions for Brushless Exciter Rectifying Modules Reduce Down Time During Overhaul", Presented at EPRI Workshop, August 2005.

[6] Schaefer, R., "Why Static Excitation?", Presented at Basler Electric Power Control and Protection Conference, October 2007.

[7] ANSI C50.13-1989, Requirements for Cylindrical Rotor Synchronous Generators.

[8] R. Schaefer, "Application of Static Excitation Systems for Pilot and Rotating Exciter Replacement," Presented at Basler Electric Power Control and Protection Conference, October 2007.

[9] Kral, D., and R. Schaefer, "Easing NERC Testing with New Digital Excitation Systems," Presented at EPRI General Meeting, January 2008.

[10] Estes, J., and R. Schaefer, "Retrofitting SCT/PPT Excitation Systems with Digital Control", Presented at IEEE/IAS Pulp & Paper Conference, June 2002.

[11] NERC Standards web site - http://www.nerc.com NERC/WECC Publication doc. http://www.wecc.biz.

[12] Kim, K., and R. Schaefer, "Tuning a PID Controller for a Digital Excitation Control System", Presented at Basler Electric Power Control and Protection Conference, October 2007.

[13] Schaefer, R., "Discussion: Excitation System Redundancy", IEEE PES Equipment Working Group of the Excitation System Subcommittee, Presented July 22, 2008.

APPENDIX
SPECIFICATION DATA SHEET

MACHINE DATA				
Turbine-Generator Size & Mfg:	______MW	______________________________Manufacturer		
Turbine Drive Type:		____Steam	____Gas	____Hydro ____Diesel
Is this a *Voltage Regulator* System Retrofit project?			_____yes	_____no
Is this a *Static Excitation* System Retrofit project?			_____yes	_____no
What is the environment at the Exciter Cubicle (dry, wet, dirty, etc.)? ______________________________				
Describe Conditions	____			
What is the Ambient Temperature of the equipment location?			______________________________	
Does system have a *Main Rotating Exciter*?			_____yes	_____no
What is the existing *System Control* Power?			_____125VDC	_____250VDC
Is 120VAC *Control* Power available in the exciter cubicle?			_____yes	_____no
What is the Excitation Power Source?				
Static Exciter:				
Generator Output			_____yes	_____no
Station Power			_____yes	_____no
Rotating Exciter Voltage Regulator Applications				
Generator Output			_____yes	_____no
PMG (Permanent Magnet Generator)			_____yes	_____no
Station Power			_____yes	_____no
Specify Station Power Voltage:	__________			
Where Station Power is used, is backup ac Station with power transfer switch required?			_____yes	_____no

GENERATOR DATA			
Manufacturer:	____		
Frequency:	____		
MW:	__________________	MVA:	__________________
Voltage:	__________________	Power Factor:	__________________
Stator Amps:	__________________	Generator Full Load Field Amps: _____	Field Volts: _____
Generator at 115% MVA at 105% generator voltage		Field Amps: __________	Field Volts: ______
Rated Generator Field Voltage:	__________________	Generator Field Ohms:	__________________
RPM:	__________________	Coolant Type:	__________________

MAIN ROTATING EXCITER DATA				
Armature Voltage:	__________________	Armature Amps:		__________________
KW:	__________________			
Exciter Shunt Field Ohms:	__________________	Rated Exciter Shunt Field Voltage:		__________________
Full Load Exciter Shunt Field Amps:	__________________			
Is this a *Brush Type* Exciter?			_____yes	_____no
Is this a *Brushless* Exciter?			_____yes	_____no
What are the ratings of the Permanent Magnet Generator?	____Volts	____Amps	____Hz	____# of phases

ADDITIONAL FEATURE CONSIDERATIONS BEYOND THOSE SPECIFIED IN TABLE 1		
Is *black start* required?	_____yes	_____no
Is a redundant *digital controller* needed?	_____yes	_____no
Are redundant *SCR Bridges* required?	_____yes	_____no
Will a *Power System Stabilizer* be required?	_____yes	_____no
Will a *PSS Tune-up* be required as part of this project?	_____yes	_____no
Is automatic transfer to redundant instrument PTs required?	_____yes	_____no
Is turnkey install required?	_____yes	_____no
Is commissioning required by manufacturer?	_____yes	_____no
Special Field Forcing Requirements?	_____yes	_____no
Define: ____		
Special Power Potential Transformer Consideration?	_____yes	_____no
Define: ____		
Is Excitation Model Information required?	_____yes	_____no
Field Ground Relay?	_____yes	_____no
Automatic Synchronization?	_____yes	_____no

DRAWING DOCUMENTATION
Schematic Interconnect Drawing
Outline Drawings
Other Special Drawing Considerations

If you have any questions or need additional information, please contact **Basler Electric Company**.
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