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TEST RESULTS FOR TRANSIENT EXCITATION BOOSTING AT GRAND COULEE

by

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ABSTRACT - Development of transient excitation boosting (TEB) hardware by the Bureau of Reclamation is a direct result of a request from Bonneville Power Administration (BPA) to install system voltage boosting hardware on the six Third Powerhouse generators at Grand Coulee Dam in Washington State. This paper presents a brief discussion of what the TEB hardware is and how it was designed and installed. The majority of the paper deals with the test results from the hardware commissioning on each generator type. The results show that an 8 percent boost in terminal voltage results in about a 50 percent change in reactive power loading and about a 10 percent change in real power with the classical high-frequency damped oscillations which are typical of a step response.

KEY WORDS - transient excitation boosting, excitation systems, automatic voltage regulator, embedded microcomputers

INTRODUCTION

Development of transient excitation boosting (TEB) hardware by the Bureau of Reclamation is a direct result of a request from Bonneville Power Administration (BPA) to install system voltage boosting hardware on the six Third Powerhouse generators at Grand Coulee Dam in Washington State. This hardware provides transient voltage support on the 500-kV transmission system in the Pacific Northwest during specific relaying actions associated with the Celilo-Sylmar High-Voltage Direct-Current Intertie[1,2]. The equipment at the Celilo Converter Station detects a double pole trip of the HVDC Intertie with power flowing to the north and generates a transfer trigger signal over a microwave communications system to the Third Powerhouse at Grand Coulee.

As depicted in Figure 1, the plant microwave equipment in the Third Powerhouse relays the trigger signal to each of the six TEB units. These TEB units are located in the excitation system cabinets adjacent to each generator stator housing. If the TEB unit is armed from the control board, the trigger signal will initiate an 8 percent boost in terminal voltage on that generator. If the associated TEB unit is not armed, then no action is taken.

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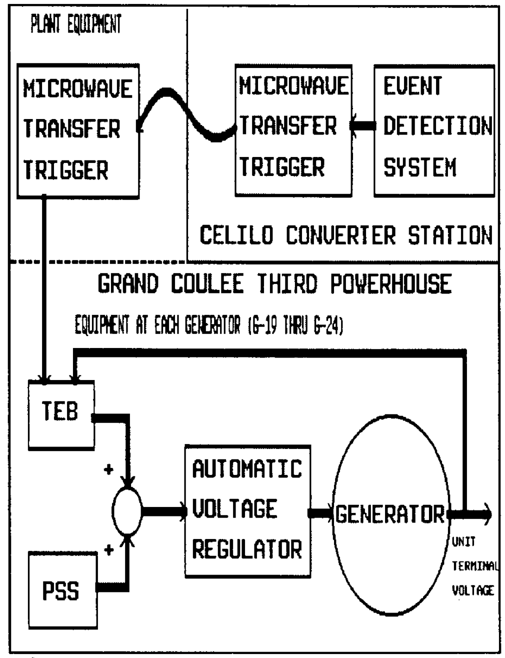

Figure 1 - TEB System Block Diagram

IMPLEMENTATION

The TEB hardware was implemented using an embedded microcomputer and associated interface and isolation electronics[3,4]. The choice of a microcomputer-based design was the result of several basic needs for the hardware. First, the system had to be reliable so as to be available when called upon to generate the boost signal. Second, the waveform generation process needed to be flexible and readily changeable. Third, the hardware needed to be maintainable by field personnel.

The system reliability issue is a very important part of the TEB design philosophy. Since the hardware is passive for long periods until called upon to generate a short-duration waveform, continuous diagnostics needs to be performed to check hardware availability. The waveform generation can be easily implemented in analog electronics with two or three op-amps and some resistors and capacitors, but the ability to diagnose a problem in this type of circuitry is limited. On the other hand, a computer is readily capable of monitoring its operation. Thus, with some minor external hardware, the microcomputer in the TEB units continuously checks the availability for waveform generation. The implementation includes the limit checking of all power supplies and signal generation hardware, as well as the normal RAM, ROM, and CPU checks used in most computer diagnostic configurations.

The waveform generation firmware implements the block diagram shown in Figure 2. The definition for the first two blocks of the diagram was supplied by BPA. The trigger signal from Celilo Converter Station generates an interrupt

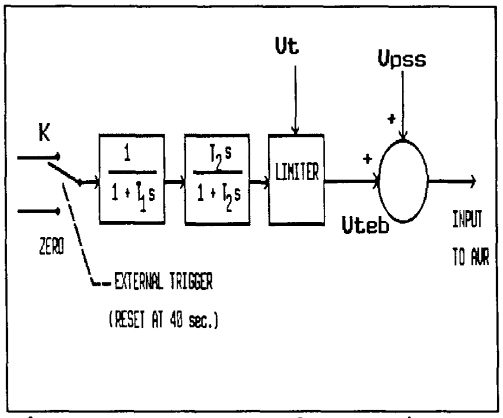

Figure 2 - TEB Block Diagram for waveform generation

to the computer at which time the computer produces the defined analog voltage waveform. The output of the TEB is held at zero volts until triggered and then exponentially rises to the value of K in per unit of terminal voltage with a time constant of T_1 seconds. At this point the second block in Figure 2 becomes dominant and the waveform changes to an exponential decay to zero with a time constant of T_2 seconds. Since the exponential decay never reaches zero, the computer resets the output to zero at the reset time of T_r seconds. The present values for these parameters are:

- * K = 0.080 pu of terminal voltage
- * T_1 = 0.1 second
- * T_2 = 10.0 seconds
- * T_r = 40.0 seconds.

The limit function of the third block in Figure 2 was implemented to keep the terminal voltage of the generator from exceeding a preset value. This limit checking is done in the computer firmware by measuring the three phases of terminal voltage, V_t, through potential transformer secondaries directly and using the largest peak value. This peak value is compared against the limit parameter, and if the input value is larger than the limit value, the computer output value is reduced by a retreat parameter amount. The peak value of the input terminal voltage is again checked against the limit value, and if it is still larger, the output is reduced by the retreat amount. This process continues until the terminal voltage is below the limit parameter value or the output from the computer is at zero volts. This overshoot is due to the delays in the control loops and is about 1 to 2 percent of nominal terminal voltage for these generators.

After the terminal voltage value is below the limit value, the output is held at this level until the decaying waveform value falls below the limited output value. When the waveform value is at or below the held value, the computer resumes generating the waveform to the automatic voltage regulator. The limit function is a hard limit at the preset value with overshoot retreat and bumpless transfer between sections. Figures 4 and 6 show this limiting process. The present values for the limit parameters are:

- * limit = 1.100 pu of terminal voltage
- * retreat = 0.010 pu of terminal voltage.

The waveform generation algorithm is in firmware on the computer, which means that the characteristics of the waveform can be easily changed. If the system tests show that a different waveform is needed, then the computer firmware can be readily changed to produce the new waveform on demand. This implementation provides the greatest flexibility.

The third reason for using a computer-based TEB unit was to provide the most maintenance-free implementation possible for the field. Since the computer is self-checking, it can identify the problem for the maintenance personnel. The design is modular in construction with plug-in boards and interconnection cables with modular connectors. Thus, the mean time to failure is high due to the use of industrial components and external connection protection, as well as continuous diagnostics. The mean time for repair is very short due to on-site spare parts and modular construction.

INSTALLATION

Modification of the existing generator excitation systems for installation of the new hardware went very well. The generators were installed from 1968-78. The first three generators (G-19 through G-21) were Westinghouse units, and the last three (G-22 through G-24) were Canadian General Electric. All generators have fully static, self-excited excitation systems.

The TEB hardware is approximately the size of a standard power system stabilizer (PSS). The TEB was mounted in the electronic cabinet of the excitation system close to the automatic voltage regulator and PSS.

The generators were taken out of service one at a time for the TEB hardware installation and wiring modifications. When the installation was completed, each generator and associated control circuitry were recommissioned as though the unit was new. This procedure gave the best opportunity to test all systems and ensure that the generators were in good working order. The excitation system testing included off-line and on-line alignment checks at various loads with and without PSS.

The TEB units were checked off-line first to ensure that the boosting and limiting functions worked correctly along with the protection and control circuitry. The on-line testing consisted of terminal voltage boosts at light loads (about 100 MW) and then boosts near full load. The results for the first two generators that were recommissioned are given in the next two sections.

G-20 TEST RESULTS

The first set of TEB hardware was installed on G-20, which is a 615-MVA, 0.975-p.f. Westinghouse generator with continuous overload rating of 690 MW at 15.0 kV and an excitation system rated at 5000 Adc or 1600 vdc maximum. Figure 3 shows a manually triggered TEB boost at 550 MW and 0 MVars as initial conditions. Figure 4 shows a boost with and without limiting of the terminal voltage. The other two Westinghouse units show the same test results, and all three work alike.

G-24 TEST RESULTS

The second set of TEB hardware was installed on G-24, which is a 718-MVA, 0.975-p.f. Canadian General Electric generator with continuous overload rating of 805 MW at 15.0 kV and an excitation system rated at 7000 Adc or 1500 vdc maximum. Figure 5 shows a TEB boost at 750 MW with the PSS unit armed and disarmed. Figure 6 shows a boost with terminal voltage initially high so that limiting occurred in the TEB unit with PSS armed and disarmed. Figure 7 shows the same strip chart channels without limiting and with PSS armed and disarmed. The other two Canadian General Electric units show the same test results, and all three work alike.

CONCLUSIONS

The data validated the model of the new excitation system function called transient excitation boosting or TEB installed in the Third Powerhouse at Grand Coulee Dam. This function is in addition to the standard PSS function and can be used with or without PSS. It can be added to any excitation system hardware that has an automatic voltage regulator with an auxiliary input to the summing junction.

The unit tests showed that a TEB boost produces an 8 percent increase in terminal voltage, a change of 300 to 350 MVars in the out direction, and a peak-to-peak swing of 50 to 90 MW with PSS armed and disarmed, respectively. Thus, an 8 percent change in terminal voltage results in about a 50 percent change in reactive power loading and about a 10 percent change in real power with the classical high-frequency damped oscillations which are typical of a step response. These results are for one generator boosting and the other five generators normal.

The system tests with BPA, which will involve several TEB units and associated generators boosting in unison, have not been performed as of this writing.

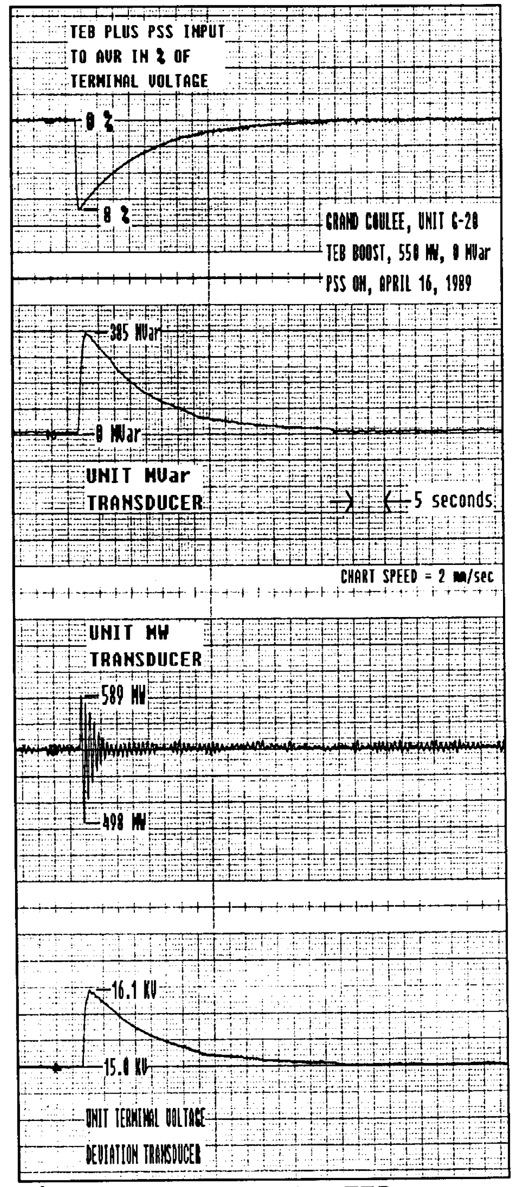

Figure 3 - G-20 TEB power system parameter tests

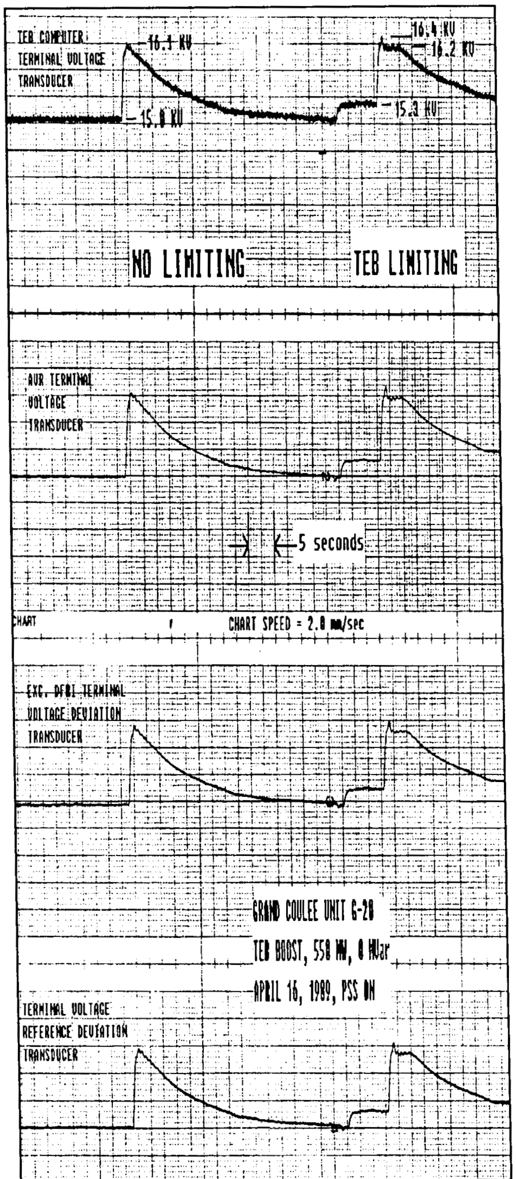

Figure 4 - G-20 TEB terminal voltage limiting tests

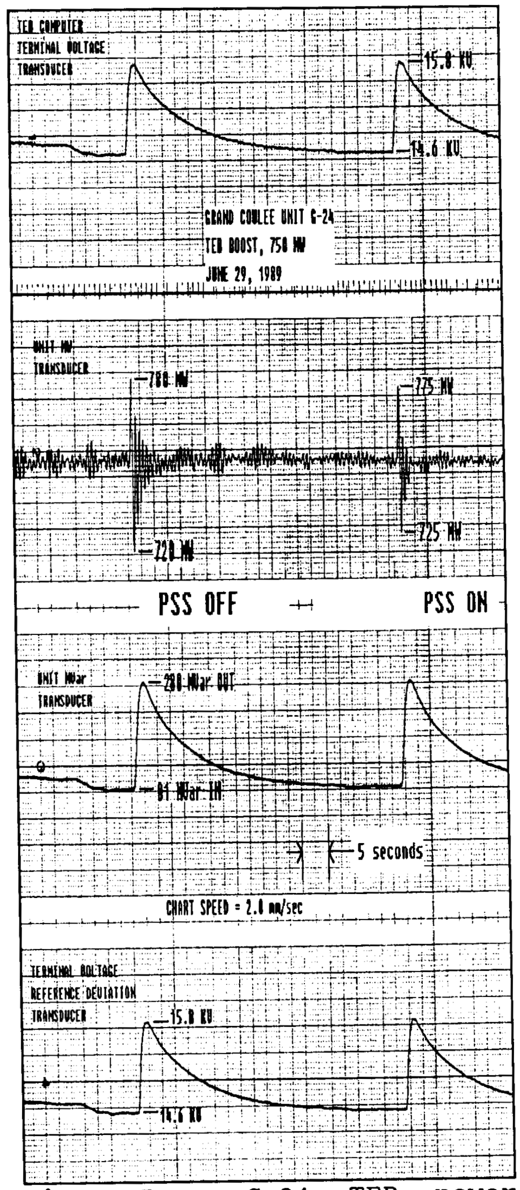

Figure 5 - G-24 TEB power system parameter tests

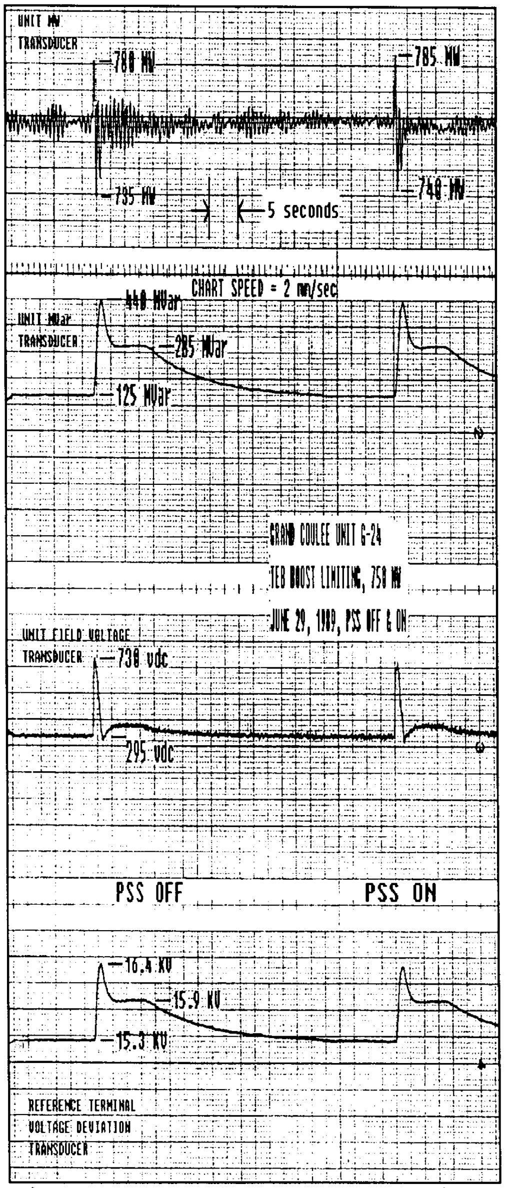

Figure 6 - G-24 TEB terminal voltage limiting tests

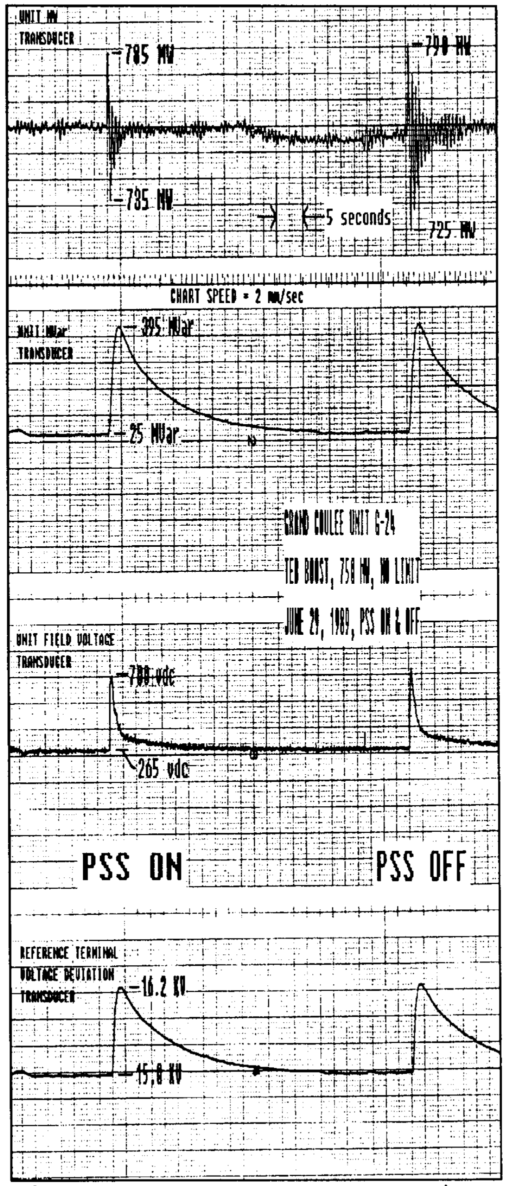

Figure 7 - G-24 TEB field voltage tests

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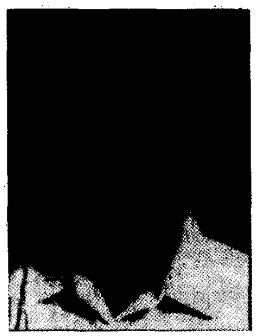

Charles A. Lennon, Jr., P.E., was born in Worland, Wyoming, on June 23, 1951. He received his BSEE from the University of Colorado, Boulder, Colorado, in December 1973 and his MSEE from the University of Toledo, Toledo, Ohio, in August 1975. Chuck has been involved in the electric power industry since 1975 with the last 11 years being with the Bureau of Reclamation at the Denver Office. He leads the developmental , research activities for Reclamation in the areas of powerplant automation and computer control systems. He is an active member of IEEE with membership in the Power Engineering Society and Computer Society. Chuck is a registered Professional Engineer in the State of Colorado. Chuck is active on the Automation Working Group of the Hydroelectric Power Subcommittee of the Energy Development and Power Generation Committee of PES.