TEST PROCEDURE FOR POWER SYSTEM STABILIZERS

INTRODUCTION

Power system stabilizers (PSS), formerly called excitation supplementary controls, are an important tool in maintaining system stability for low frequency system swings. The Western Systems Coordinating Council (WSCC) has recommended that all large generators equipped with continuously acting voltage regulators should have PSS installed with proper alinement and be in service as much as possible. Computer studies and experience have shown that intertie damping suffers greatly if even a small percentage of PSS is not in service when these generators are on line. The correct alinement procedure will further enhance the usefulness of PSS and allow their response to be more predictable, especially for computer and planning studies. The techniques described in this procedure will provide a guide for obtaining correct alinement. Unfortunately, every question or problem faced in each installation of PSS cannot be included. Thus, the WSCC Test Procedures Task Force may be consulted if unusual problems arise. PSS data may be reported using the sample form shown in Appendix I. A maintenance procedure is suggested in Appendix II.

The function of PSS is to change generator terminal voltage during low frequency oscillations such that terminal voltage varies in phase with system frequency swings or generator speed changes. PSS units are designed to use frequency or speed signals, provide the proper signal conditioning, and drive the voltage regulator to cause the terminal voltage to change with frequency. If the PSS, acting through the excitation system, can control voltage as stated above at frequencies between 0.1 and 0.5 Hz, it will provide damping to the power system and thereby aid in the stability of the power system.

This procedure does not provide background into the control theory necessary to understand the control process. Many technical papers and publications are available for this purpose (see Appendix IV). The procedure only discusses the methods for setting each PSS adjustment without discourse on all the effects a given dial setting has on the control loops. However, the following block diagram (Figure 1) is shown to provide a link between PSS instruction books and this procedure. The transfer functions (each block in Figure 1) are in terms of the Laplace variable, "s," but knowledge of the Laplace concept is not required to complete an alinement.

The blocks need not be in the order shown. Sometimes the reset circuit appears before the lead-lag stages, and sometimes the gain may be in more than one amplifier stage. However, the blocks are similar to a series circuit and their positions may be interchanged. The only exception is the limit block which must always be the last block.

This alinement procedure applies only to PSS with speed or frequency inputs. Terminal voltage deviation input in parallel with frequency is available in some installations but has usefulness only in very special circumstances and is not normally used, so it is not treated in this procedure. However, terminal voltage deviation input for a switching or limiting function is considered.

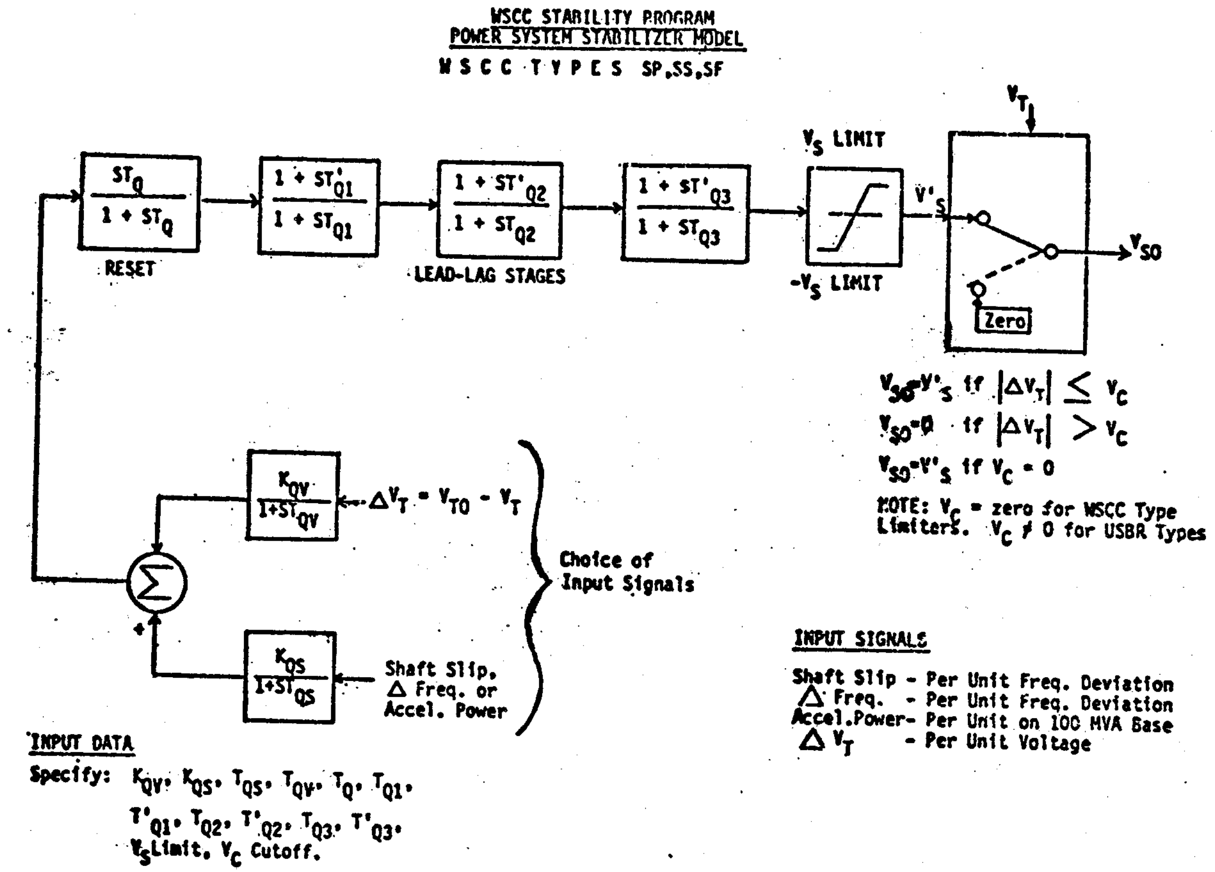

Figure 1

PREPARATORY CHECKS OF THE EXCITATION SYSTEM

The purpose of the PSS is to compensate for the phase lag of the excitation system over a band of system swing frequencies. Thus, the response of the excitation system is required before the adjustments are made. The generator should be operating connected to the power system with normal or rated loading. A signal generator (see instrumentation description) should be connected to the auxiliary input of the last PSS stage (see Insertion and Calibration of PSS Signal). A step signal should be applied and the generator terminal voltage response recorded. Should any instability, extremely slow damping (longer than ten seconds to damp the oscillations), or excessive overshoot (greater than 160 percent) be apparent, the excitation system manufacturer should be consulted. Otherwise, the excitation system may be assumed to have reasonable adjustments and the PSS alinement may proceed.

INSERTION AND CALIBRATION OF THE POWER SYSTEM STABILIZER SIGNAL

The output of the PSS must be inserted at the reference summing junction within the voltage regulator.*

When the PSS is used with a magnetic-amplifier type voltage regulator, its output signal may be summed into a spare input of the first or second stage control winding. If the regulator does not contain a spare input or control winding, the PSS signal may be summed with the existing input by means of a resistive summing network. The generator voltage sensing signal may have to be isolated from ground when the PSS signal is summed into an existing control winding. This can be accomplished with the use of a set of one-to-one isolation transformers connected in a delta-delta configuration. This isolation will break a 60 hertz ground loop between the PSS common and the generator sensing signal ground.

When the PSS is fitted to a rotating-amplifier type voltage regulator, a power output stage may be required. With this type, a resistive network is also required to sum the signal into the existing control field.

On new regulators, a spare or auxiliary input is usually available at the summing point of the appropriate operational amplifier.

A convenient means of calibrating the input signal to the voltage regulator from the PSS and also to provide a consistent format to calculate the gain of the system is to follow the procedure below:

1. Generator at full load.**

2. Voltage regulator in service. Other unit's regulators should be off if these units are paralleled on a low voltage bus with the test unit.

3. All limits within stabilizer at full range.

4. Connect a variable d-c source to the input of the last voltage amplifier of the PSS (the input from the PSS to this amplifier should be disconnected).

5. The last stage voltage amplifier should be set at unity gain for better control during this test.

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*As shown for "Other Signals" in Figure 1 of IEEE Committee Report, "Computer Representation of Excitation Systems," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-87, pp. 1460-1464, No. 6, June 1968.

**Throughout the procedure, full load conditions are assumed. However, under certain operating restrictions, tests may have to be performed at lower loads. Appendix III discusses testing at other than full load.

6. With the PSS in service, slowly adjust the test voltage and output loading adjustment of the amplifier so that with a one (1) volt change in the PSS output, the last stage voltage amplifier, a 1 percent change will be produced at the operating terminal voltage of the generator. For use later, the change in PSS output is defined as a value, E_d, equal to a terminal voltage change of 1 percent.

   If the PSS last stage voltage amplifier does not have an adjustable load resistor on its output, by proportion calculate the output voltage (E_d) of the PSS needed to change operating generator terminal voltage by 1 percent. This value will be used to set limits and determine the final d-c gain of the PSS.

7. The polarity of the PSS output signal that causes an increase in the generator terminal voltage should be noted.

After the above calibration and polarity tests are completed, characteristic data of the stabilizer output vs. terminal voltage, unit MVARS, and generator field current should be tabulated. These values will be convenient in subsequent adjustments of the stabilizer limits.

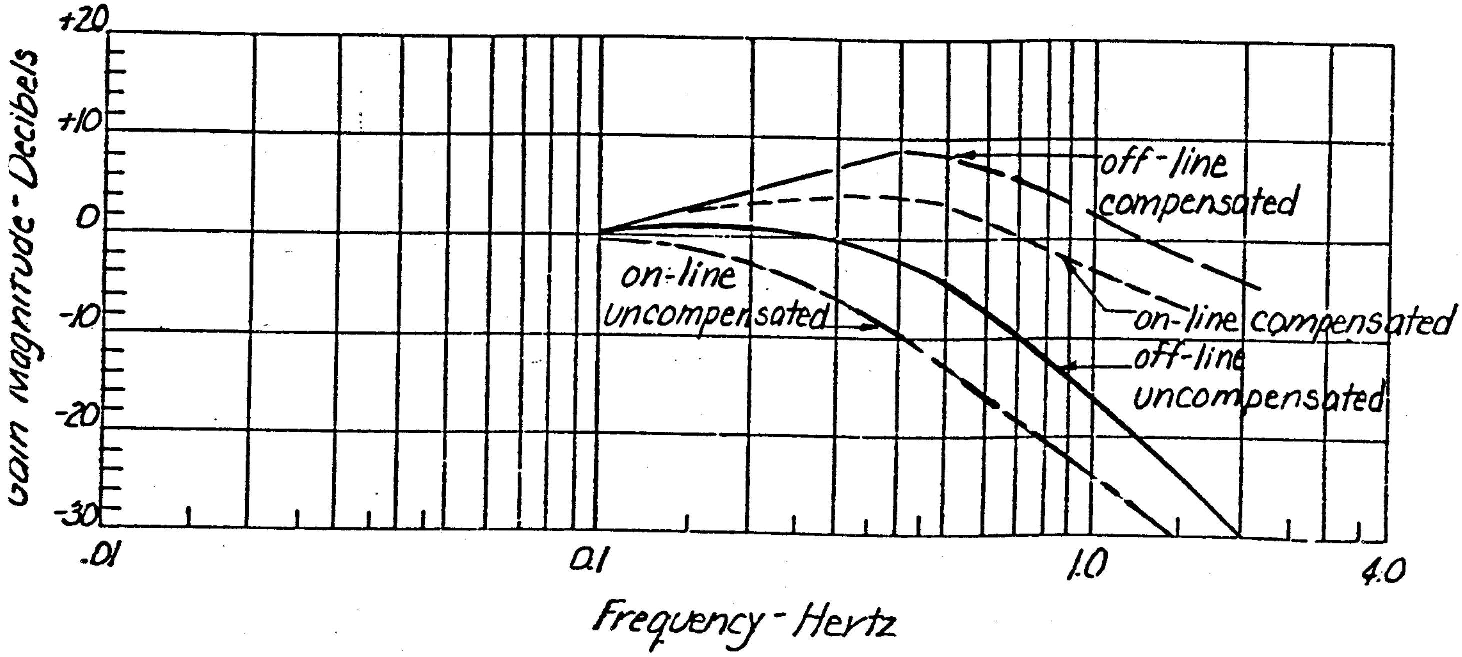
Caution should be exercised when making connections to the PSS or when removing or changing circuits or circuit cards. Some PSS designs must operate with the power supply common floating with respect to ground. All recorders, scopes, and meters must be used in a floating configuration or sudden, excessive generator voltage changes will occur. Always transfer the voltage regulator to "manual" before changing cards or circuits since the inputs to the regulator may change bias or load levels even with the PSS power supply turned off. Occasionally, the PSS power supply is also used for "manual" or "base" excitation circuits. Extreme care must then be exercised since shorting the power supply may cause loss of excitation.

FREQUENCY RESPONSE OF EXCITATION SYSTEM AND GENERATOR

The essential data needed to adjust the PSS to a particular generating unit may be obtained by measurement of its overall frequency response including voltage regulator, exciter, and generator. This should be accomplished with the generator operating at full load. The PSS on adjacent generation (generators tied to a common bus) should be removed from service during the frequency response test. Figures 2, 3, and 4 illustrate some typical response plots.

To obtain the frequency response data, insert a sinusoidal driving signal of various frequencies from 0.01 to 3.0 Hz. This signal can be applied at the same point where the calibration signal was inserted in the previous section. Readings of 0.01, 0.03, 0.07, 0.1, 0.3, 0.7, 1.0, 3.0 Hz are recommended. Record both input control signal and response of terminal voltage. An a-c to d-c transducer and zero offset voltage device (bias) should be used to record terminal voltage as a deviation quantity so that the phase and amplitude variations may be accurately resolved. The recording may be made with a direct-write or oscillographic recorder.

Grand Coulee-Unit 5-108 MVA
USBR Design, Thyristor Regulator



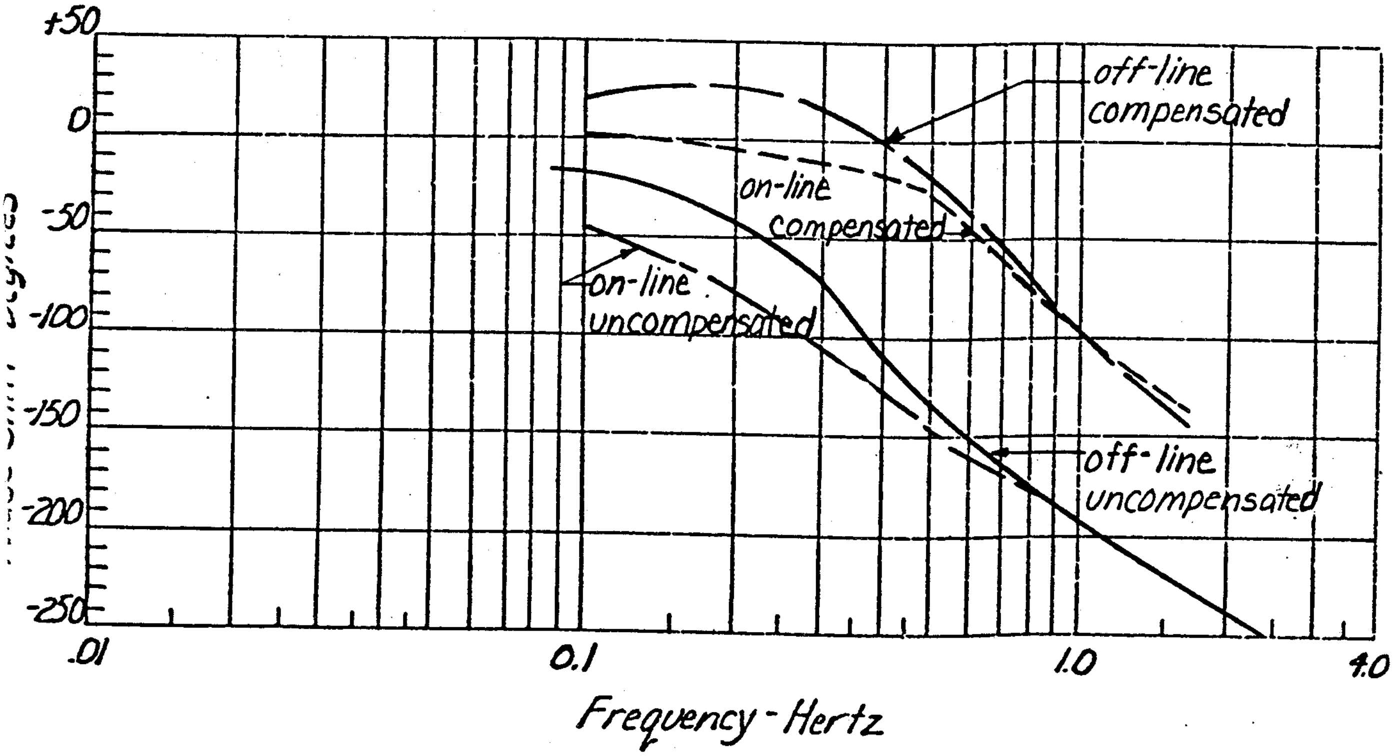
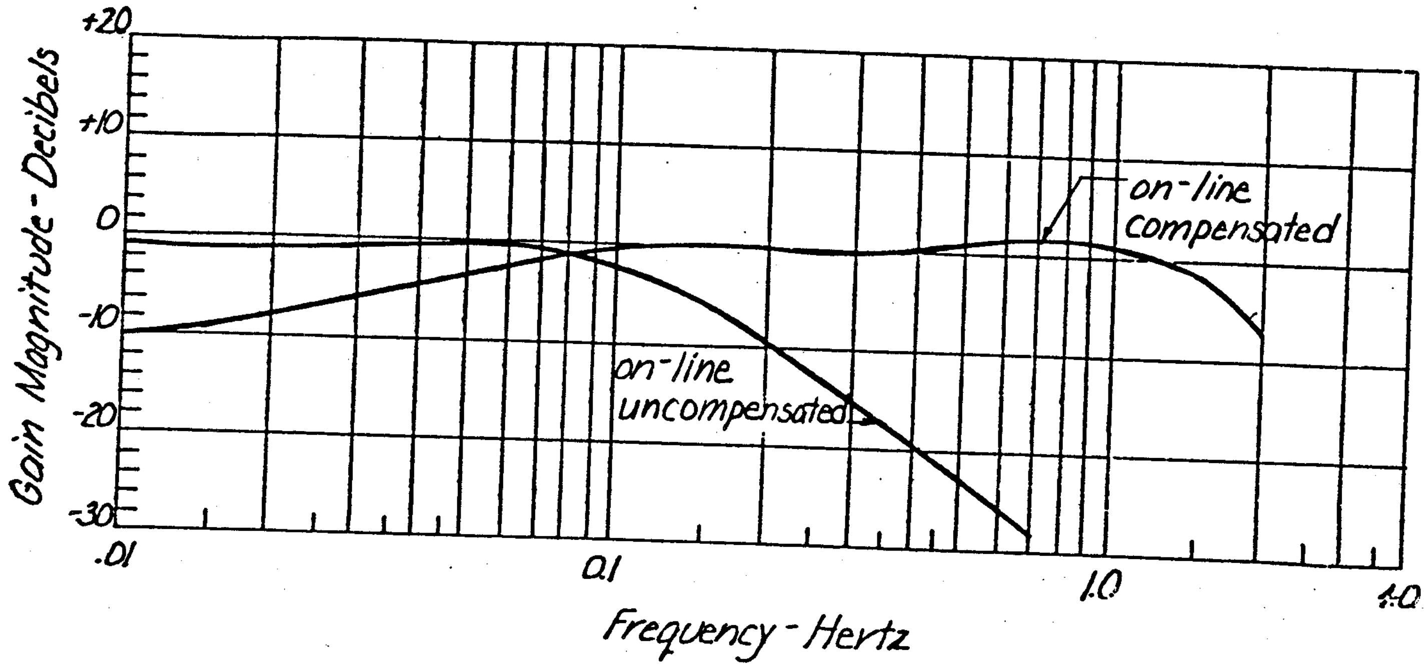


Figure 2

Pittsburg P.P. Unit 4 (PG and E)
169 MVA Tandem Compound
G.E. - NA 101



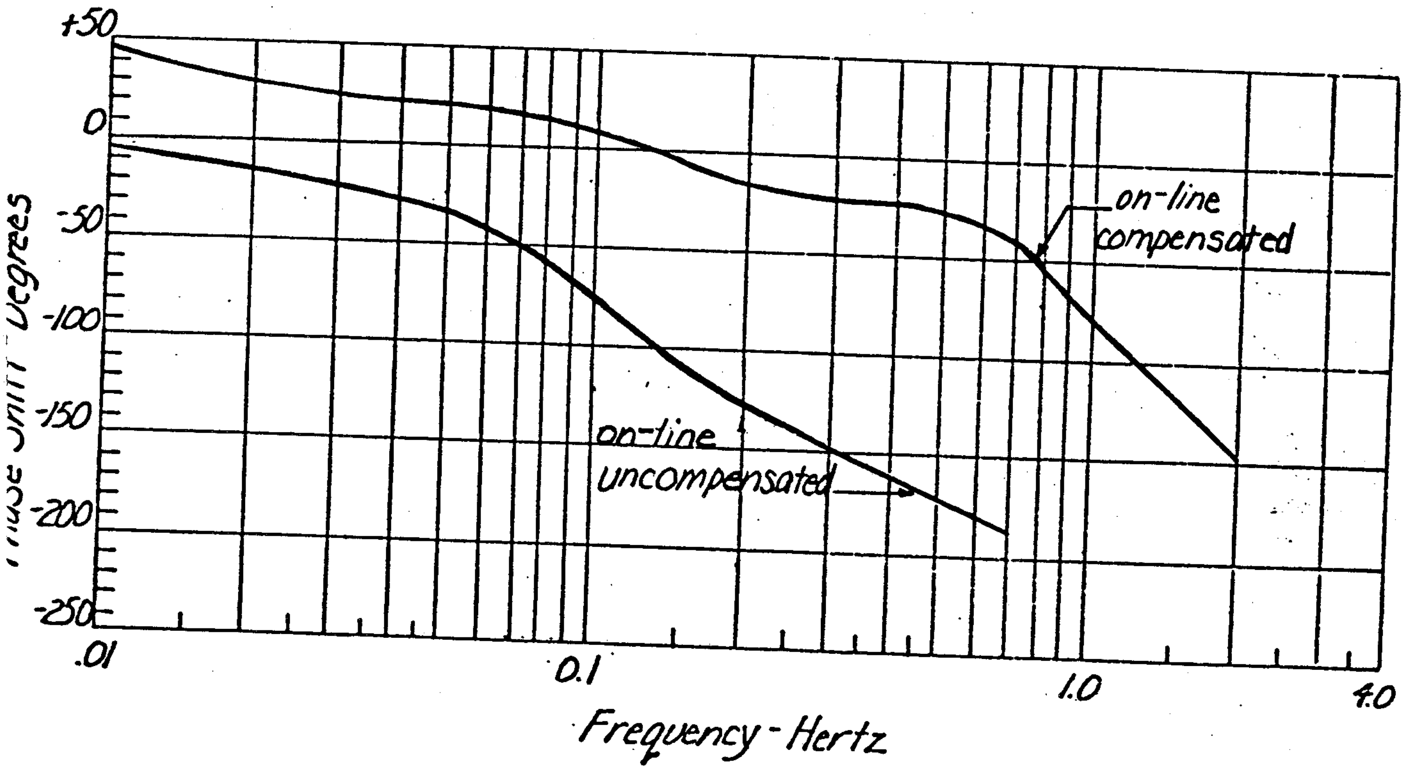
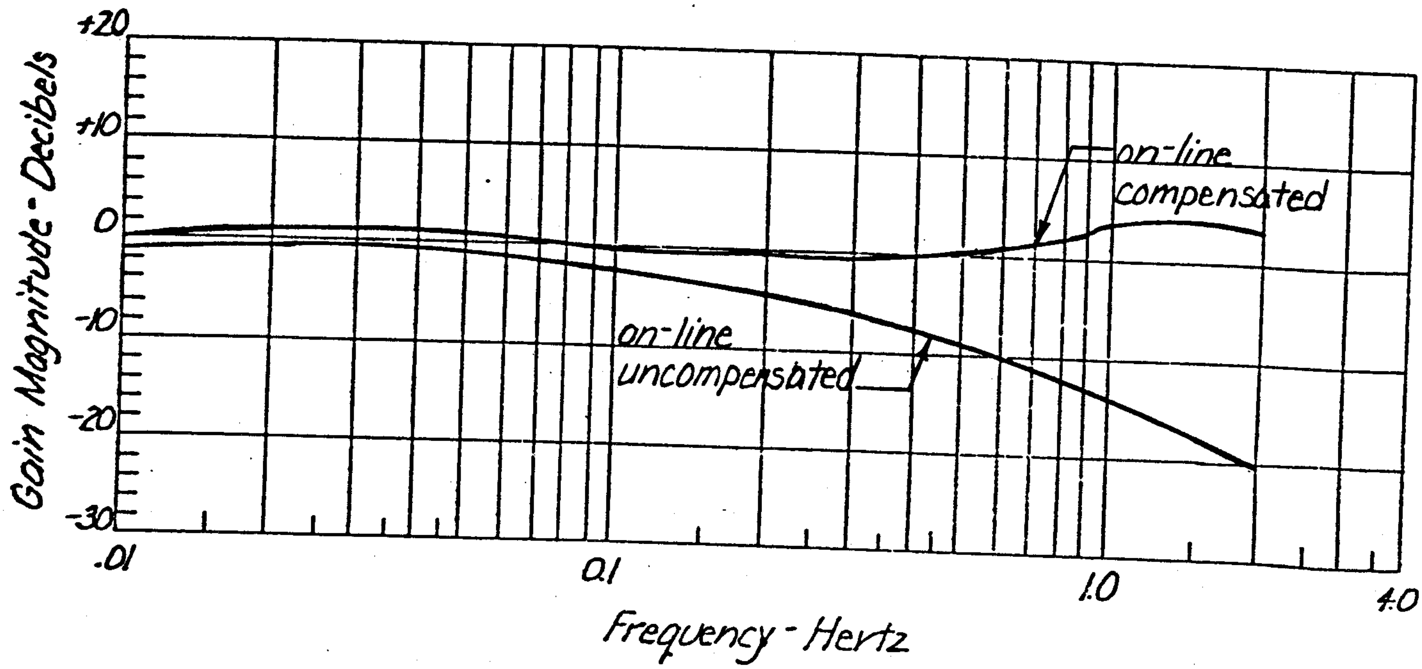


Figure 3

Moss Landing P.P. Unit 7 HP (PG and E)
750 MVA Cross Compound
G.E.- NA 143



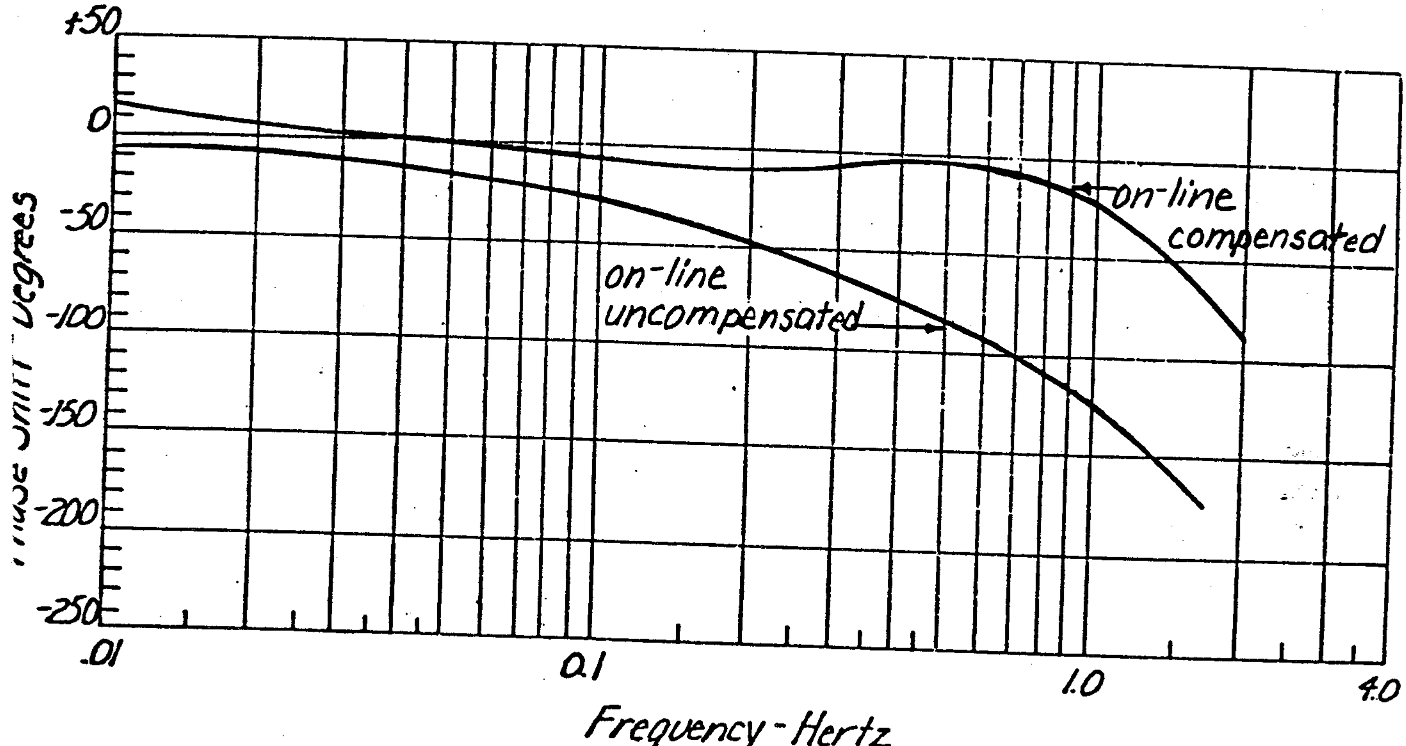


Figure 4

The driving signal should be kept as small as possible while giving readable variation of terminal voltage. Some filtering of the signals being recorded is permissible and no correction of frequency response is necessary if identical filters are used in the recorder channel for driving signal and the recorder channel for response. If a frequency response analyzer is used, any filter used on the signal and response circuits should be measured with the analyzer over the frequency range of the tests and all excitation tests results corrected for phase and amplitude at each frequency. Ordinarily about 1-2 percent variation of terminal voltage is sufficient for scaling phase and amplitude. This will require a comparatively small driving signal at 0.01 Hz and a progressively larger signal at the higher frequencies. Care should be taken that VAR swing is within acceptable limits and that the regulator is not driven to its ceiling at the higher frequencies, as this nonlinearity would invaldidate the results. A third recorder channel or scope connected to the regulator output is a convenient means of assuring that the regulator is always operating in its proportional response range. Local machine resonance (also referred to as local mode oscillation) usually occurs between 1 and 2 Hz. Exciting the local resonance should be approached with caution. Shaft vibration may become noticeable at resonance if the driving signal is too high.

Phase and amplitude data should be taken from the recordings and plotted in the form of Bode plots. A convenient form is illustrated by Figure 2. Note that the phase lag is zero if terminal voltage is at its positive (increasing direction) maximum when the driving signal is at its positive maximum. This condition will be approached at low frequencies (less than 0.1 Hz) and it should be checked that the recorder input polarities are such as to reflect this. At the higher frequencies, phase lags in excess of 180 degrees are to be expected. Phase lag data is of primary value in selecting PSS adjustments.

The amplitude information is commonly plotted in decibels:

$$dB = 20 \log \frac{(\text{terminal voltage change in \% of rated})}{(\text{driving voltage change in \% of } 100\ E_d)}$$

where E_d is the d-c driving signal required to change terminal voltage by 1 percent, as determined earlier.

Note that when the terminal voltage response in percent is equal to the driving signal in percent, the magnitude ratio is 1 and dB = 0. When the response is less than the driving signal, the dB value is negative.

SELECTION OF PHASE LEAD TIME CONSTANTS

The fundamental function of the phase shifting network in the PSS is to compensate for the phase lag in the response of the excitation system being controlled. For example, when measurements indicate the response of the machine terminal voltage lags the input voltage of the voltage regulator by 90 degrees, the power system stabilizer should provide 90 degrees of phase lead. Normally, the PSS will employ two phase advance stages. However, high initial response systems may require special compensation and are, therefore, discussed separately.

The two phase leads are shown as the two terms in the numerator T'_{01} and T'_{02} of the transfer function (see Introduction). The time constants can be approximated most readily by selecting the phase lead time constants at the frequency for which they would each provide 45 degrees of phase advance. The frequency to determine selection of these two phase advance time constants is that point where the generating unit's overall response of terminal voltage lags the voltage regulator input by 90 degrees.

Example: An example of this calculation is as follows: in Figure 2, the 90 degree phase lag point would be .25 Hz with the unit on line and uncompensated. Converted to radians, this frequency would be .25 x 6.28 = 1.57 radians per second. Each of the lag time constants would be the reciprocal of this radian frequency = $\frac{1}{1.57}$ = .64 seconds.

HIGH INITIAL RESPONSE EXCITATION SYSTEMS

Some excitation systems described as "high initial response" may also have small signal characteristics which require special alinement consideration. If the excitation system frequency response has more than 90 degrees of lag at 1 Hz, the alinement described earlier using two phase leads is correct.

If the phase response is less than 90 degrees at 1 Hz, several additional concepts should be taken into consideration. First, the frequency transducer lag must be added to the excitation system frequency response using a graphical method. The transducer usually can be considered to have a simple time constant which is available from the manufacturer.

The resulting composite curve should also be graphically smoothed to eliminate any effects of local swing resonance. Then two lead time constants should be selected as indicated in the previous discussion. However, the ratio between the lead and lag terms can be rather low to aid in noise suppression. A ratio of between 3 and 10 is often used. The compensated frequency response (described in a later section) can have as much as 45 degrees phase lag at 1 Hz without significantly degrading local oscillation damping. Noise suppression is most important and every effort should be made to concentrate gain reduction between 1 Hz and 15 Hz without sacrificing more than 45 degrees phase lag at 1 Hz. If noise is severe, one stage of lead may be used instead.

Occasionally, a PSS as delivered from the factory may not have the proper lead time constant range. These modules can be utilized by using one lead time constant instead of two (eliminate the second time constant by setting the lead equal to the lag). The lead is then set to the time constant derived from the 45 degree crossing of the excitation system response rather than the 90 degree point.

Other effects must be carefully checked when working with the faster excitation systems. Shaft torsionals are always present and the PSS may damp or undamp these torsional modes. The manufacturer should be consulted as to the seriousness and frequency of the torsional modes, and careful observations of shaft vibration should be made during alinement procedures. Transducer noise is always present and additional power system noise may be generated by nearby industry. It may be necessary to place a 55 to 65 Hz bandpass filter ahead of the transducer to provide noise relief. If the generator does not have an individual transformer, but is bussed together with another generator at generation voltage levels, shaft speed or reactive-compensated frequency is required, with the reactance set to the Xq of the generator. These signals may have higher noise levels and must be filtered.

In some cases, response for damping may be required for a frequency above local swing frequency to compensate for local industrial loads such as arc furnaces. Then the stabilizer may have to employ three lead functions. However, shaft torsionals and noise problems become paramount and advice from other PSS users should be sought.

SELECTION OF PHASE LAG TIME CONSTANTS

Some phase lag terms are necessary to limit the amplification of hum and noise in the control system. The time constants of these filter terms (denominator terms of the transfer function) necessarily must be a compromise choice between noise and limiting of the useful frequency range of the control. Assuming that there are two stages of lead compensation, there must be not less than two lag terms, but there may be more. The time constants of all these filter terms except one can be as small as practicable. In general, time constants in these terms in the order of 0.01 second will cause no concern provided there is one filter time constant of approximately 0.1 second. Also, for minimum vulnerability of the channel to saturation by fast changes of the input signal, the longest filter time constant should be first in the chain.

Ability to use small time constants will depend largely upon the quality (ripple or random noise) of the frequency or speed signal and upon the amount of phase correction required. When an extreme amount of phase lead (120 degrees or greater) is needed to compensate the overall response at the most critical frequency for system oscillation, which is presently about 0.3 Hz, it may be necessary to keep all of the lag time constants very short, but this presents a severe compromise between noise vulnerability and phase compensation.

SIGNAL LIMITS

1. Dynamic or Hard Limits

The last stage of the PSS before the signal is inserted into the excitation system contains a signal limiting circuit. This is usually comprised of diodes around the last operational amplifier controlled by two potentiometers. If a single control for the two potentiometers is used, the limits are made symmetrical in the circuitry. If two adjustable controls are available, they should be set to obtain symmetrical plus and minus limits.

The need for these limits is to provide a dynamic range for the PSS signal and eliminate any unsymmetrical limiting caused by previous stages. The limits are for the transient response and not for steady-state operation. Thus they are usually set to ±10 percent of the insertion signal base. Be sure that both the base and the limiting voltage are measured at the output of the PSS limiting stage. Thus if 1 volt d-c of PSS output will cause the generator terminal voltage to change 1 percent (see "Insertion and Calibration of PSS Signal"), the limits should be set to ±10 volts. Do not attempt to set the limits by actually driving the terminal voltage (or field current) 10 percent as there might be nonlinearities present and the machine may be driven past normal MVAR capabilities. Rather, disconnect the PSS from the excitation system. Connect the speed deviation or frequency deviation signal and increase the PSS gain setting until the PSS output voltage is large enough to be limited on both the plus and minus excursions. Then set the limits to clip the signal at the voltage calculated above. Alternatively, connect a ± power supply to the input of the last stage voltage amplifier and measure the output voltage of the PSS. Then increase the input voltage until the PSS output voltage is large enough to be limited on either polarity. Set the limits so that with a 10 to 13 volt input the output is limited at the voltage calculated above. These values are considered the hard limits. As the input voltage is reduced, the value at which clipping, or limiting, just starts to occur should be noted. This value should be less than 75 percent of the hard limit.

If the excitation system cannot tolerate ±10 percent limits because of field forcing alarms or similar problems which will become apparent during the compensated frequency response test, the limits should be lowered to eliminate the problem but should not be set below ±4 percent.

Some PSS users prefer to use ±10 percent of field current to cause hard limiting. Although the result is the same as using +10 percent of PSS drive signal for off-line conditions, the on-line dynamic limits change as load changes and usually provides equivalent limits of about ±7 to 9 percent of PSS drive signal. However, these limits can be field checked by driving the PSS output until field current changes the required 10 percent and then setting the limit. Be careful to make the limits symmetrical and do not change generator Mvar beyond operating capabilities during the tests.

2. Steady-State Limiting and Protection

Since the dynamic limits provide a wider range of signals than can be tolerated in steady-state operation, several methods may be used to obtain security from driving the excitation system beyond the normal ±5 percent steady-state operating limits (or at least 1 percent below the hard limit settings). These methods include voltage-sensitive switches, auxiliary timing circuits, and limiter meters.

The voltage-sensitive switch usually measures generator terminal voltage and disconnects the PSS signal from the excitation system when the terminal voltage exceeds a preset limit. The voltage transducer should be calibrated in d-c volts change per percent terminal voltage change (measured during the calibration of the insertion channel). Then the settings for the switching point can be calculated from the curves provided in the instruction manuals for ± 5 percent terminal voltage change from rated voltage. If operating conditions require a larger range, the limits should be set about 2 percent outside the normal operating range.

The auxiliary timer method uses a circuit to monitor the PSS output level, and if the level exceeds a preset limit for a given time, the PSS signal is removed from the excitation system. The level sensitivity should be set to ± 5 percent of the PSS output signal base (or one-half the dynamic limit setting) with a time of about 7 seconds. This would allow normal ± 10 percent excursions for a 0.05 Hz system swing without removing the PSS from service.

The limiter meter method works in a similar manner to the auxiliary timer. The meter has a photo detection system which picks up a timer device if the adjustable limits are exceeded. The limits and timer should be set in the same manner as the auxiliary timer above.

In all cases, tests should not be made to verify settings unless the generator is off line as excessive MVAR output may result. However, the levels and times may be checked with the PSS disconnected from the voltage regulator just as dynamic or hard limits were set.

3. Protection from Overvoltage During Load Rejection

When a generator is tripped from the line while loaded, a speed rise follows. If speed deviation is sensed or if frequency deviation is derived from generator terminal voltage, the PSS will sense a rise in the input signal. The generator voltage will then be driven upward, possibly causing generator overvoltage. Several methods may be used to limit the overvoltage effect.

The first common method is to interlock the PSS output with a permissive contact on the generator breaker controls. Thus the PSS is in service only when the breaker is closed. When a load rejection occurs, the breaker opens and the PSS is disconnected from the generator.

The second common method is to use the voltage sensitive switch described in 2. above to detect the overvoltage condition and remove the PSS signal.

RESET TIME CONSTANT

The reset function (also called washout) incorporated in the PSS allows the influence on voltage from any sustained deviation of speed or frequency to gradually subside. Choice of reset time constant is not critical except to keep its phase shift from interfering with normal control operation.

In the range of frequencies for which additional system damping is important, reset serves no function; it should introduce no phase shift. Incidental to accomplishing the gradual resetting, it inherently causes a phase lead at very low frequencies. The effect is inverse to that of the lead-lag stages of the phase compensator which must contribute increasing phase lead with increasing frequencies. Interference between these two functions is minimized by making the reset time constant long. Effectiveness of damping and convenience of testing have both been shown to be benefited by a long reset time constant, while no particular advantages have been found in making the reset time constant short. Consequently, a reset time constant of about 30 seconds is recommended.

GAIN DEFINITION AND VERIFICATION

The gain of the PSS, as considered here, is the d-c or steady-state gain, exclusive of the reset (washout) function. It is thus the ratio of the change in generator terminal voltage in percent to the change of speed or frequency, in percent, causing that change of terminal voltage. In other words, a gain of four would be reflected by a change in terminal voltage of 4 percent for a 1 percent change of speed or frequency (0.6 Hz).

This gain can be verified conveniently by experimental means by inserting a small step signal in place of (or in addition to) the speed or frequency deviation signal and measuring the response of terminal voltage (see Figure 5). If the reset feature of the PSS is left operative during this test, the response of terminal voltage will gradually subside and it will be necessary to extrapolate it back to the instant the step signal is applied to obtain the proper value of terminal voltage response. It is usually more practical to disable the reset function during this test and to have the PSS gain set at unity.

For example, with the General Electric 3S7932LA100, LA101, LA102 PSS, the step signal test for gain may be conveniently accomplished by the use of the "Jog" button. It has been observed that when this button is depressed, the tachometer signal decreases by 0.3 percent (individual sets should be checked if possible). A resulting decrease of terminal voltage by 1.2 percent would indicate a gain of 4.

According to the Westinghouse Type F7 PSS manual, their frequency transducer has a sensitivity of 1 volt/hertz. Therefore, a step signal test for gain may be made by applying a -0.3 volt step signal instead of the frequency deviation signal. Application of the -0.3 volt step is equivalent to a 0.5 percent increase of frequency. Thus, if terminal voltage of the controlled generator increases 2 percent, the PSS gain is indicated to be 4. Reset may be eliminated in this apparatus by shorting out the reset capacitor on the signal reset card with a small jumper.

FREQUENCY RESPONSE OF EXCITATION SYSTEM COMPENSATED WITH PSS

As a final check on adequacy of the PSS adjustments, the frequency response of the overall system should be checked to verify that the PSS network adequately offsets the phase lags in the voltage regulator, exciter, and generator. This check is made according to the same procedure as for the initial frequency response tests except that the driving signal is fed into the PSS apparatus in place of the frequency or speed deviation signal, and the output of the PSS is connected to the voltage regulator.

If adjustments have been adequate, the phase lag will be nearly zero over the useful range as shown in Figure 2. A compensated phase shift of ±30 degrees at the intertie swing frequency is considered acceptable. The gain curve will also be reasonably flat over this range.

Readjustments of time constants may be made and the check rerun, if necessary.

Note that with the gain curve nearly flat, unlike in the initial frequency response run, it will not be necessary to increase the driving signal as the frequency is increased. However, care will again be necessary that the regulator is not driven to its limits by the higher frequencies.

SETTING OF GAIN

Within certain limits to be described, a gain as high as practicable is recommended for best contribution to system damping. While a relation between gain and inertia of the unit could ideally bring about equal sharing in angular swing among the generating units during a system disturbance, this would hold only for the highly idealized condition of all units being equally loaded and responding to PSS control. But since allocation of load among generating units must vary widely from time to time and since not all generating units can be equipped with PSS, a practical compromise is necessary. Since the maximum gain which is safely usable depends upon many factors, it is best determined by test.

A test for the maximum safely usable gain may be made as follows: with the PSS fully operative and either PSS output or generator terminal voltage deviation being recorded, slowly advance the gain until a small rapid oscillation, usually in the frequency range from 1 to 3 Hz, is just sustained. High initial response systems may oscillate at 4 to 8 Hz. Note this value. For good stability of the control loop, the gain should be reduced to about one-third this value. In this determination of gain, care must be taken that the PSS signal is not being clipped by the limits. Noise and other spurious components in the control signal increase as the gain is increased. If they should reach the point of being clipped by the limits before the oscillation is sustained, influence of the PSS is diminished and a false indication of allowable gain will result. In severe cases, the limits may so nullify PSS action that no oscillation can be produced. If a sustained oscillation cannot be obtained because of large blocks of parallel generation not controlled by PSS, then set gain to one-third the point of clipping.

If shaft torsionals are of concern, an occasional analysis of the PSS output on a strip chart recorder, run at high speed, will indicate whether or not the torsional is being excited. The PSS gain should then be reduced to one-third the value where shaft torsionals begin.

It is important that this test for usable gain be made under the most sensitive conditions to which the unit will be exposed in normal service.

(a) The unit should be at full load* with a leading power factor. Only then is the influence of excitation control at its maximum.

(b) If the unit under test may be required to operate radially on 50 miles or more of line, the gain margin should be established for this condition.

(c) If the unit operates only in parallel with other units which are not equipped with PSS, it may be tested under this condition. The safely usable gain will be higher than if operating alone because the inertias of the parallel units are effectively combined.

(d) If the unit is to operate in parallel with other units which are also equipped with PSS, a correct result is obtained only when gain of the PSS on all paralleled units is advanced simultaneously. Although this can be a simple matter where a single PSS serves all generating units in a plant, the simultaneous advance of gain on a number of individual PSS units could be quite tedious. If so, an approximate result may be obtained with the control operative on only one or two of the paralleled units, by adjusting the result accordingly. Tests have shown the gain to sustain oscillation is about inversely proportional to the number of units responding to control. Thus, if self-oscillation appears at a gain of 36 operating on one unit among four in parallel, a gain of 9 on the control of all four units operating simultaneously would sustain the oscillation. For a safe gain margin, the gain should be reduced to 3 on each unit.

With several units in a plant, the stabilizer gain to sustain oscillation may be allocated among the units in any proportion. However, in so doing, differing MVA ratings among the units must be recognized. For example, a gain of 6 on each of two 100 MVA (6 x 100 = 600) units along with a gain 3 on one 300 MVA unit (3 x 300 = 900) is equivalent to a gain of 15 on one 100 MVA unit. Thus, in testing for gain to sustain oscillation, the gains and MVA ratings of other units on the same bus should be considered. For good stability margin, the total gain x MVA product should be reduced to one-third that which just sustained oscillation. It is good practice for operation to distribute the gains uniformly among similar units.

Conversely, if a gain sufficient to sustain oscillation on one unit cannot be obtained, the maximum gain obtainable on one unit divided by three times the number of units will result in less than the maximum gain but will insure a safe gain margin.

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*If not at full load, see Appendix III.

TESTS OF PSS PERFORMANCE ON THE POWER SYSTEM

A simple verification of alinement uses the basic PSS concept that the generator terminal voltage must be in phase with the system swing frequency deviations for frequencies between 0.1 and 0.5 Hz. Thus, if the terminal voltage and the frequency deviation or speed deviation are monitored on a strip chart recorder for about one-half hour, some small system disturbances in the frequency range of interest will usually occur.

If these disturbances, such as shown in a sample chart of Figure 6, produce voltage and frequency deviations in phase, the PSS is correctly alined. A rough check of gain may also be made by measuring frequency and voltage amplitudes and comparing them on the percent bases (1 percent frequency is 0.6 Hz). The result should be within a factor of 2 of the calculated gain. Such results should verify the alinement is satisfactory.

During these tests, remove PSS (or lower the gain) to determine the normal influences of voltage and frequency to insure that the PSS is actually contributing to holding the voltage and frequency in phase with each other.

INSTRUMENTATION

The testing and installation of the PSS is performed with the following instrumentation:

1. Signal generator:

   Sine wave 0 to 5 volts, 0.01 to 10 Hz.
   Direct current 0 to 5 volts.

2. Recorder, oscillograph, two channels (or more), with appropriate amplifiers, or storage oscilloscope:

   Frequency response, d-c to 100 Hz.
   Sensitivity, 1/2 mv/mm to 20 v/cm.
   Chart speeds, 1 mm/second to 100 mm/second.

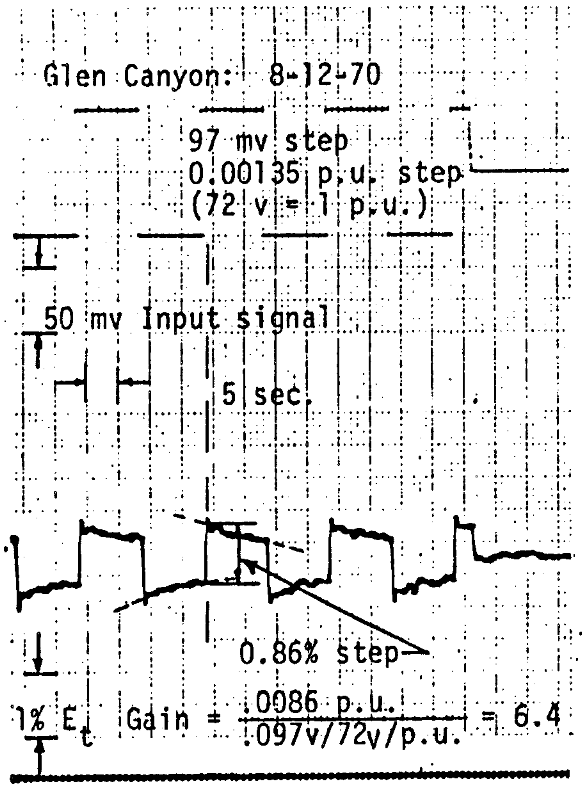
3. Voltage transducer:

   Three-phase 60 Hz, 120 volts to d-c with adjustable voltage source for suppressing zero of voltage signal similar to Figure 7.

4. Frequency deviation transducer.

5. Oscilloscope.

6. Frequency response analyzer may supplement or replace Items 1 and 2.



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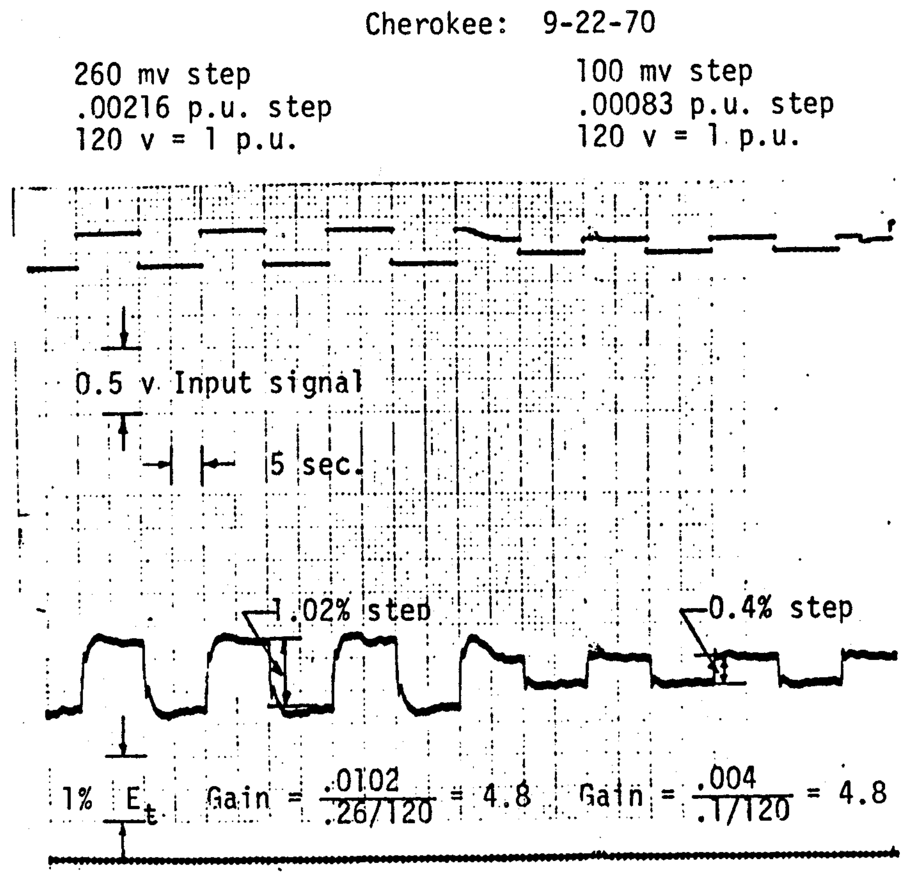


B

Figure 5. Verification of PSS gain by step signal technique.

A. With reset operative and correction to time zero by extrapolation.
B. With reset inoperative. Note that signal limiting at left affects shape of response but not calculated gain.

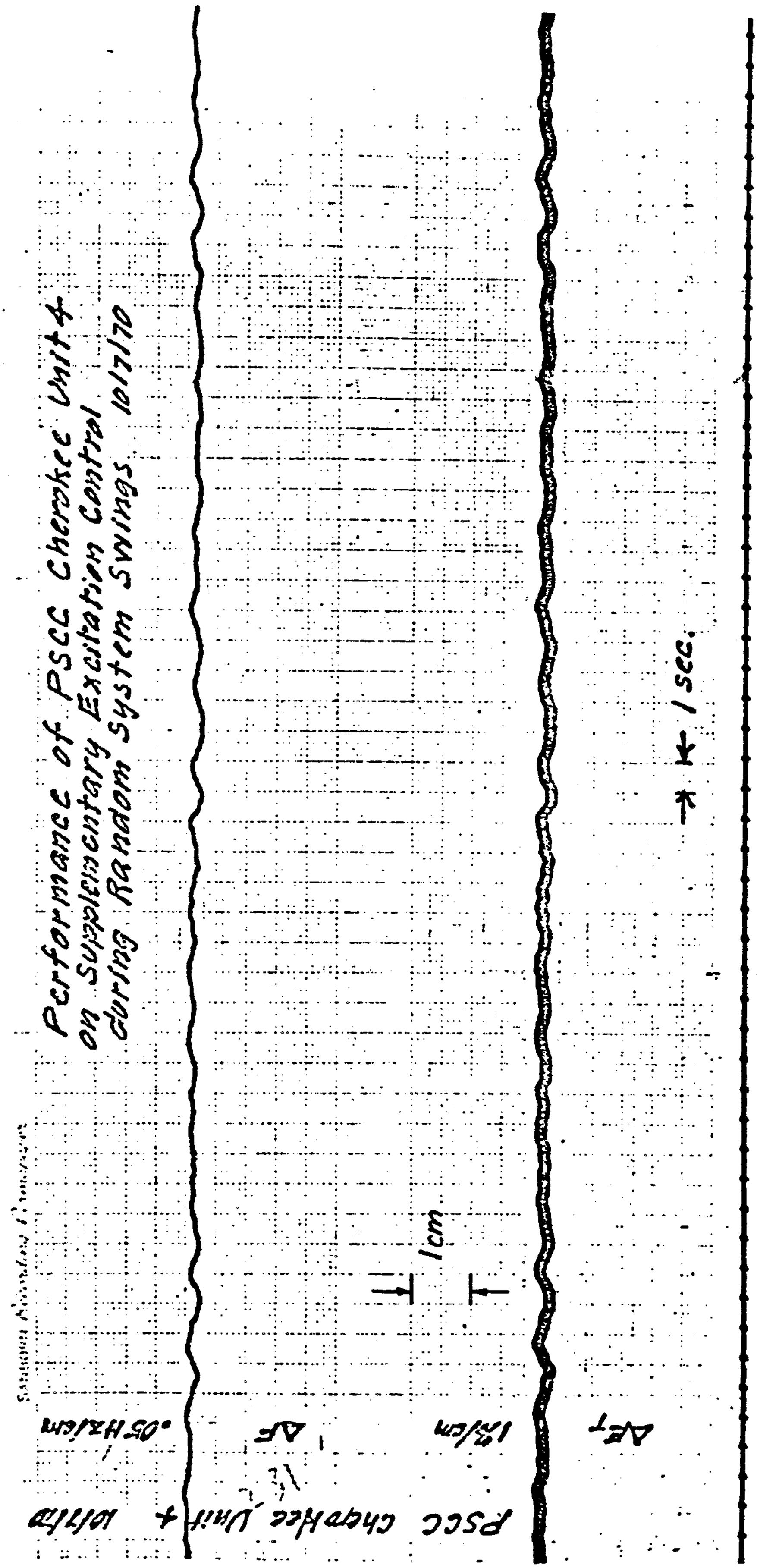
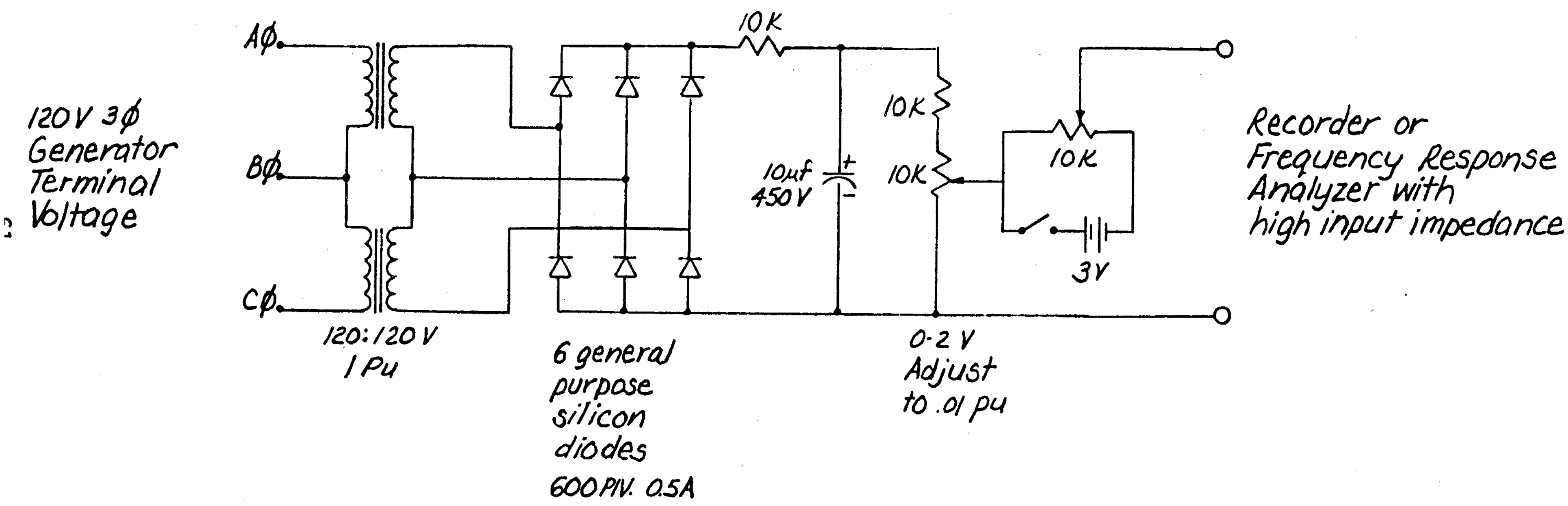

Performance of PSCC Cherokee Unit 4
on Supplementary Excitation Control
during Random System Swings 10/7/70
.05 Hz/cm
Δf
1%/cm
ΔE_T
1cm
1 sec.
PSCC Cherokee Unit 4 with

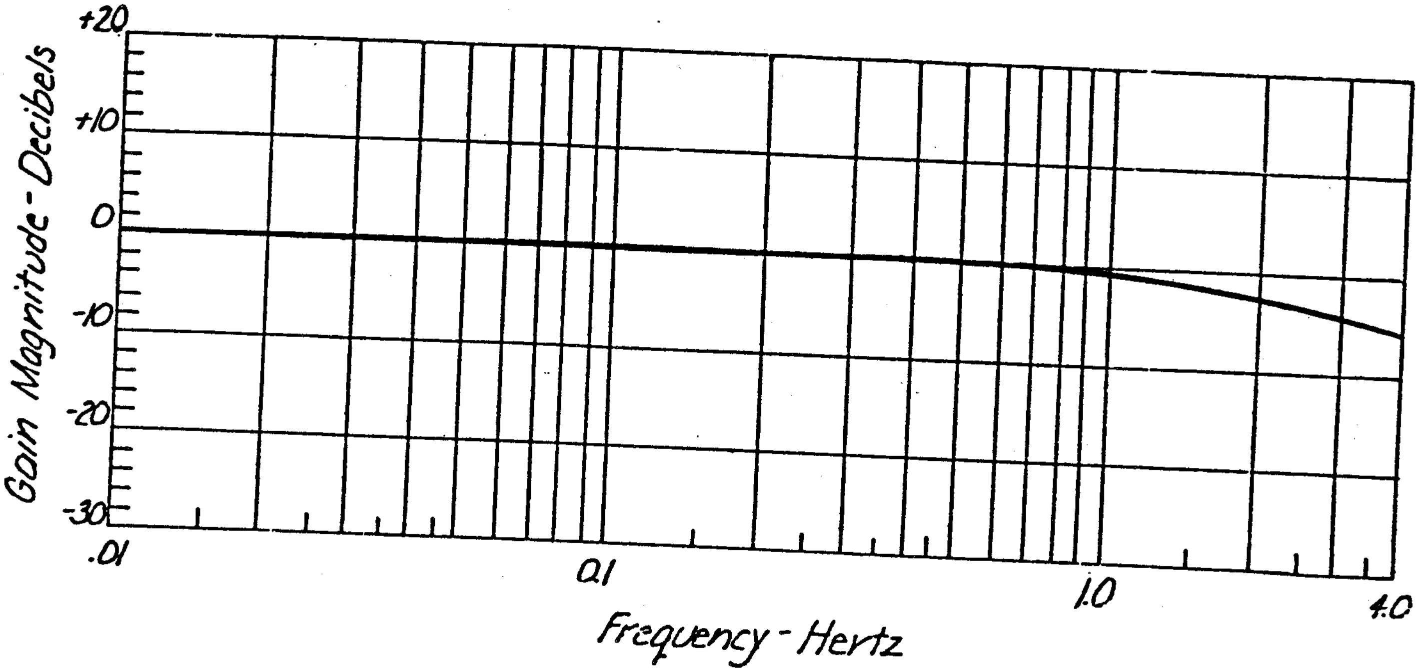
Figure 6.



Voltage Transducer Schematic

Figure 7

Bode Plot of Transducer
In Figure 7



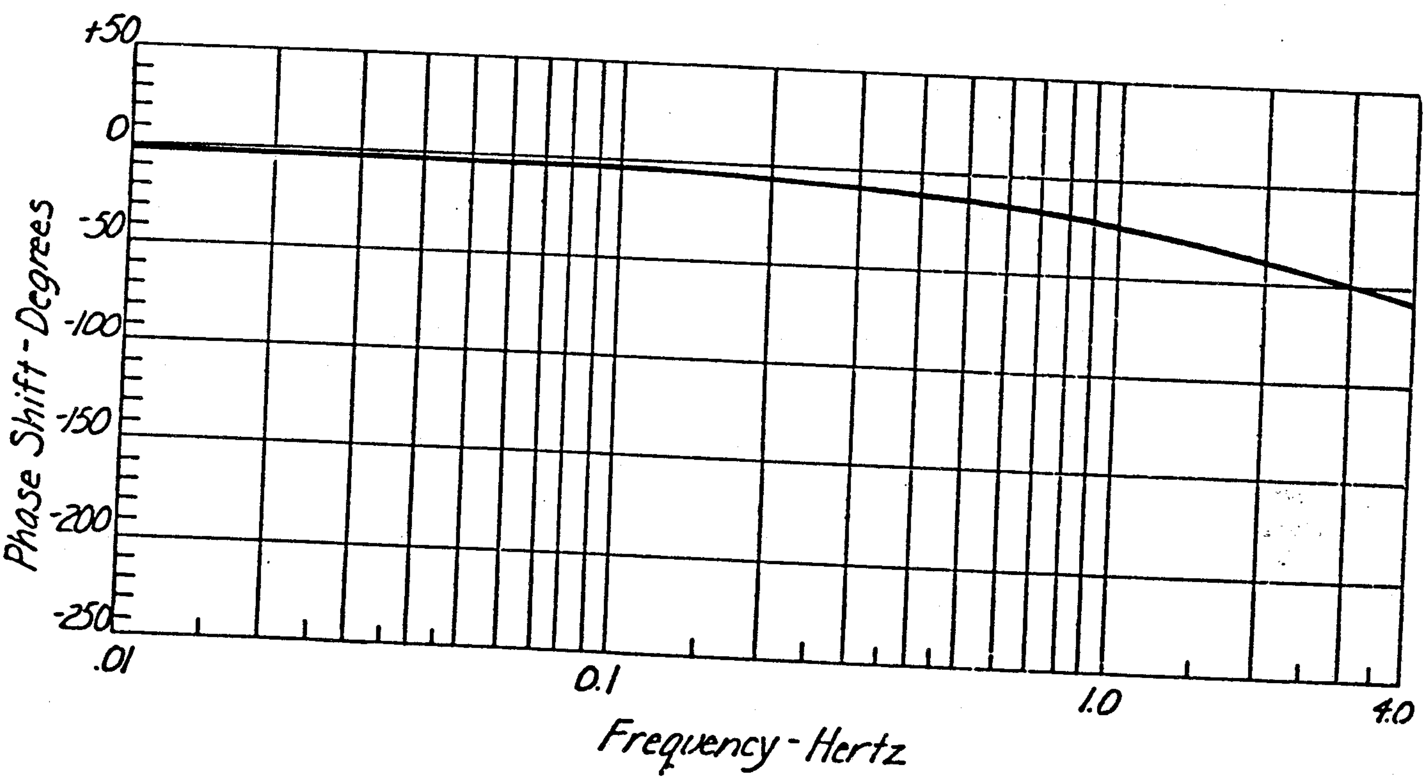


Figure 8

APPENDIX I
(Sample PSS Report Form)

PSS AND EXCITATION SYSTEM DATA

1. Name of plant ____________________ Unit ____________
2. Test dates ____________________
3. Type of regulator ____________________
4. MVA of generator ____________________
5. Generator configuration

   _____ High bus through unit transformer

   _____ Bussed to another similar generator with common unit transformer

   _____ Other (please describe) ____________________

6. Type of PSS

   _____ GE LA-101 _____ GE LA-201 _____ Westinghouse F-7

   _____ Other (give builder and model, if any) ____________________

7. Year installed ____________________
8. PSS common to more than one unit?

   _____ Yes _____ No _____ Number of generators

TEST DATA

1. Generator loading during tests ________ MW ________ MVAR
2. Type of input signal

   _____ Frequency from generator PT _____ Frequency from HV bus PT

   _____ Compensated frequency from generator PT on generator base
   Xq = ________ percent

   _____ Shaft tachometer

3. Any notch filters on a-c side of frequency transducer?

   _____ Yes _____ No Describe ____________________

4. a. Calibration of frequency transducer ______________ d-c V/Hz

_____ From instruction book

_____ Calibrated with variable frequency source

b. Calibration of tachometer ______________ V/rated RPM

5. Calibration of regulator input channel using the output stage of the PSS as a driver, __________ V d-c input changed terminal voltage ________ % (using rated voltage as a base)

6. Input channel pot settings: identify pot(s) and give setting with 10 being full pot ____
____

7. Any filtering used in the PSS?

_____ Yes _____ No Describe ______________________________________

8. Limit settings: pot(s) = ______________, ______________
Give limits of ± __________ V (referred to the input of the driver stage)

9. Lead time constant settings: pot(s) = ______________, ______________ seconds
for time constants of ______________, ______________

10. Lag time constant settings: pot(s) = ______________, ______________ seconds
for time constants of ______________, ______________

11. Reset time constant settings of range = __________, pot = __________,
for a reset time of __________ seconds

12. Jog button available? _____ Yes _____ No
Moves generator terminal voltage __________ %, Mvars __________

13. Maximum gain determined by

_____ Oscillation, max. gain = __________ at __________ Hz oscillation

_____ Describe ____

14. Gain used is ______________; pot setting = ______________
Verified by step test? _____ Yes _____ No

15. Protection

_____ Unit breaker contact

_____ Under/over voltage switch set to switch at ± __________ % generator voltage deviation

_____ Timeout limit timer or meter with limits at _____ V PSS output for _____ seconds (pots = __________, __________)

16. Special problems or comments:

Attach copy of Bode plot for excitation system without and with PSS, if possible. Mail to:

Tom Hillesland
Pacific Gas and Electric Company
Department of Engineering Research
3400 Crow Canyon Road
San Ramon, CA 94583

APPENDIX II

INSERVICE CHECKS AND PERIODIC MAINTENANCE OF POWER SYSTEM STABILIZERS

To insure the power system stabilizer is performing satisfactorily, three levels of maintenance or checks should be conducted on a routine schedule:

Level 1

Performed daily or weekly by the plant operator. Install a jog (test) button in the control room that, when pressed, will cause a small upset in the PSS and excitation system. The magnitude of the upset can be adjusted to a preset level with potentiometer, Rx, located in the PSS control cabinet (Figure II-1, General Electric, or Figure II-2, Westinghouse). The jog test would be recorded on the generator's megavar recorder located in the control room. The jog will provide a momentary offset in one direction (positive or negative depending on the PSS configuration) when pressed, and in the reverse direction when released. This test will indicate that the control is basically functional although it does not test the frequency transducer or tachometer.

Level 2

The PSS should be removed from service during these tests to avoid problems arising from inadvertent misconnections.

Performed semi-annually or annually by an on-site technician or electrician. Instrumentation required would be VOM, variable d-c source, low frequency signal generator, and oscilloscope or recorder. Accurate notes should be kept for future reference. The following tests should be performed:

1. Check power supply voltage levels and ripple components. Measure input voltage to frequency transducer (if used in place of a tachometer).

2. Measure the output of the frequency transducer or tachometer voltage and check the wave form as described in the equipment manual.

3. Check the output of each succeeding stage after the frequency transducer or tachometer. These outputs will normally be about zero volts d-c with some low frequency noise (less than 1 volt at a frequency less than 20 hertz). A large d-c offset would generally indicate an operational amplifier failure.

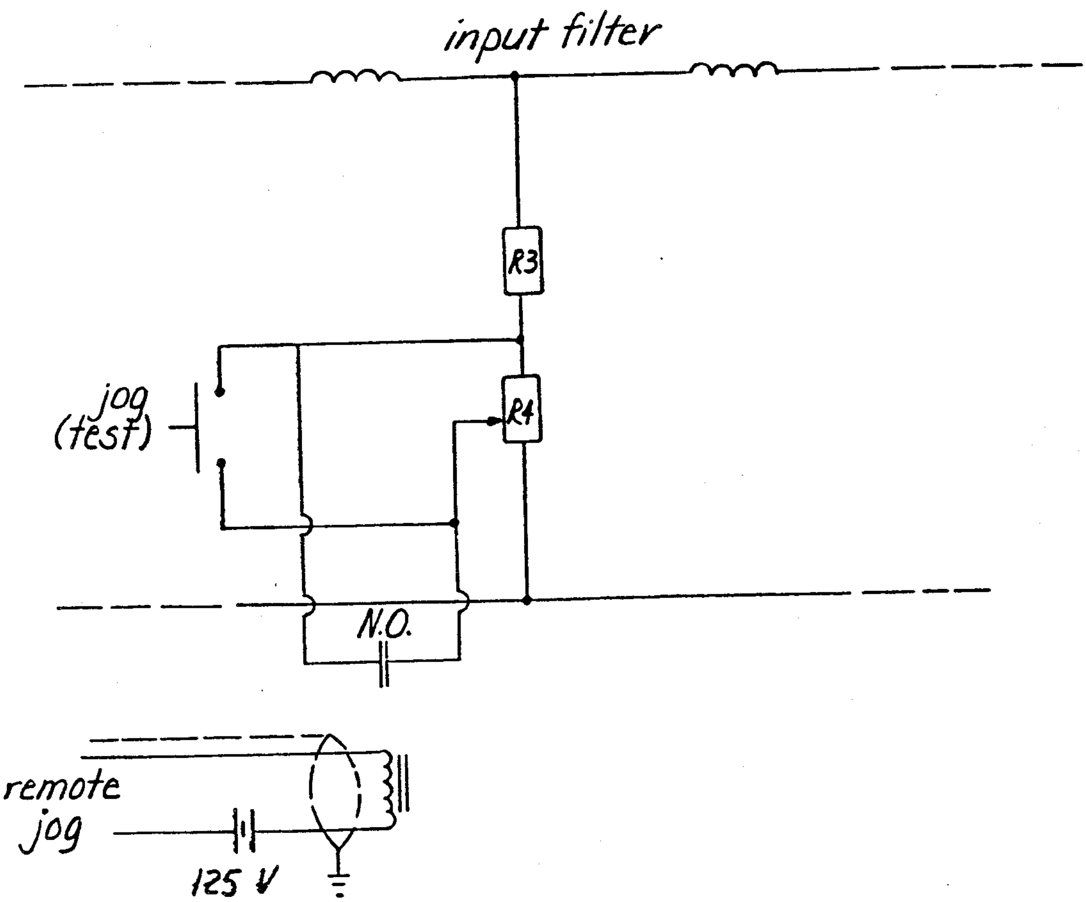
4. Disconnect the frequency transducer or tachometer output and connect a low frequency signal (1 hertz or less) to the input of the following stage. With the oscilloscope or recorder, observe the output of each succeeding stage. If only the positive or negative half of the sine wave is passed through a particular stage, a defective operational amplifier is indicated. To avoid peak clipping as the signal is amplified by the stabilizer, the signal generator output must be kept small.

5. Insert the variable d-c source (±15 v d-c) on the input of the stage which controls the limits and protective time circuits. The preceding stage should be disconnected to prevent back-feeding from the d-c source. Check for proper limiting and timing with the PSS disconnected from the voltage regulator. An alternate method for checking limits is the following. With all stages of PSS connected but isolated from the voltage regulator, increase the gain setting until the PSS output voltage is large enough to be clipped by the limit set points. An oscilloscope or recorder connected to the output should also show that both the positive and negative excursions are limiting symmetrically. It should be noted that Step 4 could be incorporated to provide the same information, especially if the gain range of the PSS is such that noise limiting may not be achieved.

The second level of maintenance will confirm proper operation of PSS with the exception of the lead-lag stage's time constant settings and that the overall gain is adequate for stable operation.

Level 3

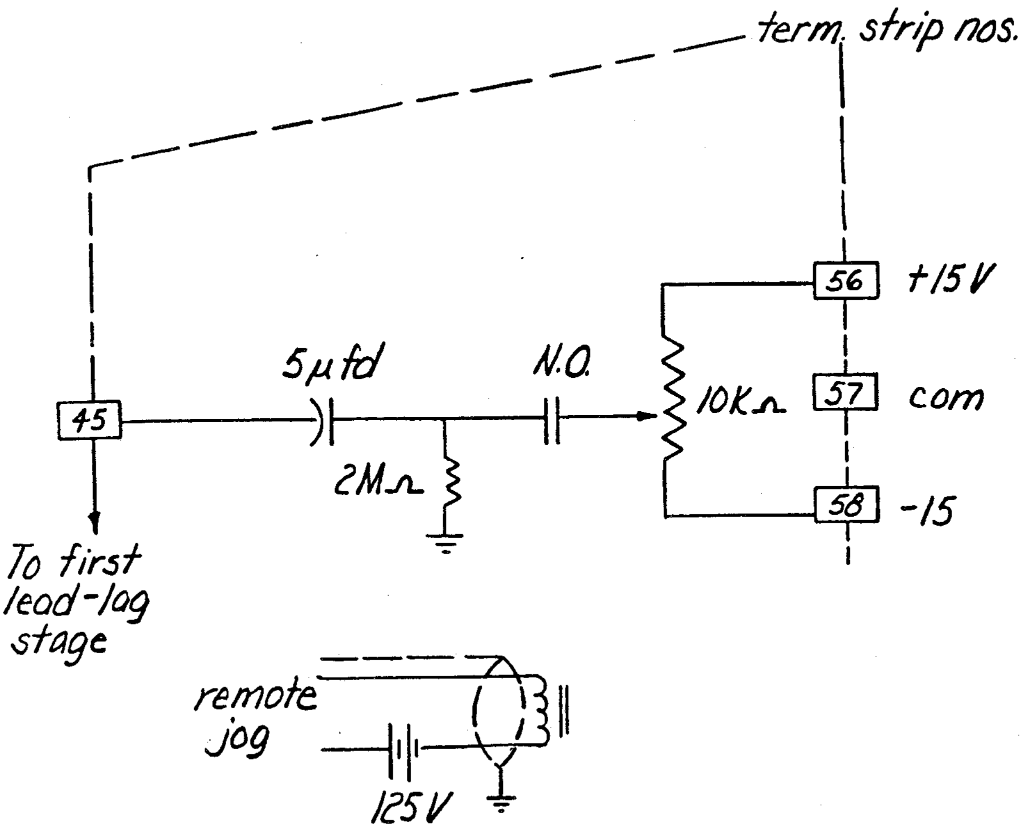
Performed on initial installation and once every five years by personnel familiar with the theory of operation of the stabilizer. The instrumentation required is listed in the WSCC Test Procedure. The tests to be performed are discussed in the procedure including the settings of the lead-lag time constants and finding the proper gain for stable PSS operation.



1. Replace R4 with 2k Ω pot.
2. Rewire jog button.
3. Adjust R4 for desired deflection of MVAR or regulator output change.
4. Remote jog can be placed in control room if desired.
5. Jog test can be made with regulator in test position if convenient.

G.E. PSS Jog

Figure II-1



1. Install 10k Ω pot across ± 15v.
2. Adjust pot for desired deflection of MVAR or regulator meter.
3. Remote jog can be placed in control room if desired.
4. Jog test can be made with regulator in test position if convenient.

<u>Westinghouse</u>
<u>PSS Jog</u>

Figure II-2

APPENDIX III

ADJUSTMENT WHEN UNABLE TO TEST AT FULL LOAD

Tests of the excitation system should preferably be done with the unit operating at or near full load. However, due to operating limitations, occasionally tests have to be performed at lower loads. The tests can be performed at half load and then adjusted for the approximate settings required for full load.

Frequency response tests will be reasonably accurate at half load, and the test results can be used directly.

However, gain tests are sensitive to load. Tests and analyses have shown that the gain at which PSS causes local mode oscillations to be sustained will be lower for full load than for half load. Therefore, if the gain test must be performed at half load, the gain margin should be doubled so as to yield normal gain at full load.

Example: Tested at half load, a gain of 12 per unit caused sustained oscillation at local mode frequency (say 1.5 Hz). Normal procedure would require dividing the gain by three for adequate gain margin (12/3 = 4). However, since the unit was tested at half load, double the gain margin by dividing by six (12/6 = 2). Therefore, the permanent gain setting would be 2.

APPENDIX IV

Selected references related to excitation systems and power system stabilizers. The first 14 references are also included in Reference 15.

1. Computer Representation of Excitation Systems, IEEE Committee Report. IEEE Transactions on Power Apparatus and Systems, June 1968.

2. Excitation System Dynamic Characteristics, IEEE Committee Report. IEEE Transactions on Power Apparatus and Systems, January/February 1973.

3. Experience with High-Speed Rectifier Excitation Systems, K. R. McClymont, G. Manchur, R. J. Ross, and R. J. Wilson. IEEE Transactions on Power Apparatus and Systems, June 1968.

4. A Rotating Thyristor Excitation System for Hydroelectric Generators, E. C. Hartung, E. H. Lenfest, and G. R. Meloy. IEEE Transactions on Power Apparatus and Systems, September/October 1972.

5. Althyrex Excitation System with Power System Stabilizer, M. L. Crenshaw, W. J. Miller, R. P. Schulz, and M. Temoshok. IEEE Paper 70 CP 563-PWR.

6. A High Initial Response Brushless Excitation System, T. L. Dillman, J. W. Skooglund, F. W. Keay, W. H. South, and C. Raczkowski. IEEE Transactions on Power Apparatus and Systems, September/October 1971.

7. Design of a Power System Stabilizer Sensing Frequency Deviation, F. W. Keay and W. H. South. IEEE Transactions on Power Apparatus and Systems, March/April 1971.

8. Field Tests of Dynamic Stability Using a Stabilizing Signal and Computer Program Verification, R. M. Shier and A. L. Blythe. IEEE Transactions on Power Apparatus and Systems, February 1968.

9. Excitation Control to Improve Powerline Stability, F. R. Schleif, H. D. Hunkins, G. E. Martin, and E. E. Hattan. IEEE Transactions on Power Apparatus and Systems, June 1968.

10. Effect of High-Speed Rectifier Excitation Systems on Generator Stability Limits, P. L. Dandeno, A. N. Karas, K. R. McClymont, and W. Watson. IEEE Transactions on Power Apparatus and Systems, Janaury 1968.

11. Improved Stability with Lower Time Constant Rotating Exciter, H. R. Perry, J. F. Luini, and J. C. Coulter. IEEE Transactions on Power Apparatus and Systems, September/October 1971.

12. Power System Stabilizer: Field Testing and Digital Simulation, A. D. Gerhart, T. Hillesland, Jr., J. F. Luini, and M. L. Rockfield, Jr. IEEE Transactions on Power Apparatus and Systems, September/October 1971.

13. Experience with Supplementary Damping Signals for Generator Static Excitation Systems, W. Watson and G. Manchur. IEEE Transactions on Power Apparatus and Systems, Janaury/February 1973.

14. Static Exciter Stabilizing Signals on Large Generators - Mechanical Problems, W. Watson and M. E. Coultes. IEEE Transactions on Power Apparatus and Systems, Janaury/February 1973.

15. Stability of Large Electric Power Systems. Edited by R. T. Byerly and E. W. Kimbark. IEEE Press. The Institute of Electrical and Electronics Engineers, Inc. New York. 1975.

16. Criteria and Definitions for Excitation Systems for Synchronous Machines. IEEE Standard 421-72, December 1972.

17. Proposed Excitation System Definitions for Synchronous Machines. IEEE Committee Report. IEEE Transactions on Power Apparatus and Systems, March/April 1971.

18. Terminology for Automatic Control. ASME, NY, NY. ANSI C85.1, 1963.

19. IEEE Standard Dictionary of Electrical and Electronic Terms. IEEE Standard 100-1972. Wiley-Interscience, NY, NY. 1972.

20. Alinement and Modeling of Hanford Excitation Control for System Damping. E. J. Warchol, F. R. Schleif, W. B. Gish, and J. R. Church. IEEE Transactions on Power Apparatus and Systems. March/April 1971.

21. Operational Amplifiers. Design and Applications. Edited by J. G. Graeme, G. E. Tobey, and L. P. Huelsman. McGraw-Hill Book Company. New York, NY. 1971.

22. Power System Stabilization with High Initial Response Excitation on Large Hydro-Electric Generators, L.E. Eilts, W. B. Gish, F. R. Schleif. Bureau of Reclamation Research Report REC-ERC-72-18, June 1972 (may be ordered from Bureau of Reclamation Publications, Denver Federal Center, Denver, Colorado).