R-89-08

HOOVER UNIT A6 EXCITATION SYSTEM COMMISSIONING TEST

September 1989

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Research and Laboratory Services Division
Electric Power Branch

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16. ABSTRACT

Commissioning tests on the uprated unit A6 at Hoover Powerplant were conducted during February 1989. Excitation system performance tests conducted at that time are described.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS--* voltage regulators/ control equipment/ electric power production/ excitation/ power system stability/ power system stabilizers/

b. *IDENTIFIERS--* voltage regulators/ power system stabilizers/ Hoover Dam/ Lower Colorado River Dams Project

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by

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Electric Power Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

September 1989

UNITED STATES DEPARTMENT OF THE INTERIOR ✱ BUREAU OF RECLAMATION

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

The research portion of the activities covered by this report was funded under the Bureau of Reclamation PRESS (Program Related Engineering and Scientific Studies) allocation No. DR-496, *"Electric Power System Stability Enhancement."*

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INTRODUCTION

Unit A6 at Hoover Powerplant was uprated as part of the powerplant modernization. A new static pilot exciter was supplied by General Electric; the previous rotating main exciter was retained. Installation and setup of the excitation system were performed by Reclamation personnel. Following completion of the uprate, the commissioning tests were performed from February 13-18, 1989.

J. Agee and Hoa Vu from the Denver Office participated with Terry Ardourel, Tom Robinson, Warren Britton, and Claude Fuller from the project in the commissioning of the new General Electric excitation system. This report summarizes the test results. Appendix A lists all special conditions that were used during the commissioning. Appendix B lists all test connections that were used to collect data during the commissioning. Appendix C lists all parameters of the excitation system as found and as left. Appendix D shows the computer model representation of the excitation control system.

CONCLUSIONS

The excitation system was successfully commissioned and the unit was placed into commercial service. The limiter associated with maximum excitation was modified with a temporary resistor to provide proper operation. This temporary resistor will be replaced with a permanent resistor of proper physical size upon receipt from General Electric.

REGULATOR ADJUSTMENT PHILOSOPHY

Since the rating of unit A6 is above 50 MV•A (megavolt amperes), a power system stabilizer was purchased for it. This unit has a rotating exciter and, therefore, its response time was rather slow. The regulator was tuned for as fast a response time as possible with a rotating exciter. With the unit off line, this resulted in a moderate overshoot. With the unit on line, the response was still rather slow, but the local mode of oscillation was well damped. The power system stabilizer would not improve the local mode unless it was re-tuned with an aggressive alignment that would produce excessive noise in the exciter voltage. Therefore, the power system stabilizer was aligned to help the other system oscillation modes instead of the local mode. Since unit A6 has its own step-up transformer, the impedance compensator was set at 0 percent so that the regulator will regulate terminal voltage.

RATINGS AND CALIBRATIONS

Unit A6 is rated at 133.33 MV•A and 0.975 power factor. The rated voltage is 16.5 kilovolts and rated current is 4,550 amperes. Full MV•A output is obtained with real power at 130 MW (megawatts) and reactive power at 29.6 Mvar (megavars).

The PT (potential transformer) ratio is 150:1 and the CT (current transformer) ratio is 5,000:5. The voltage regulator terminal voltage transducer (at terminal C of A5CB) produces 51.8 volts d.c. (direct current) at rated terminal voltage.

The base field current required to produce rated terminal voltage on the air gap line is 693 amperes (see fig. 1). The field resistance at 35 °C is 0.122 ohm. Therefore, the base field voltage is 83.2 volts. The field voltage transducer in the regulator (at terminal 4 of JVT) has a calibration of -8 volts of output for 250 volts of input. This signal has a base of 2.66 volts per unit.

The rotating exciter base field current required to produce 83.2 volts from the exciter on its air gap line is 7.6 amperes (see fig. 2). The exciter field resistance is 1.998 ohms. Therefore, the base exciter field voltage is 15.2 volts.

At 97.7 percent load (127 MW), unity power factor, the field current is 1,005 amperes; therefore, the field voltage is 122.6 volts. The exciter field voltage is 22.7 volts. The exciter field current is 11.1 amperes. At rated load (130 MW, 29.5 Mvar), the field current is 1,173 amperes; therefore, the field voltage is 140 volts. At 35 °C, the exciter field voltage is 28 volts. The exciter field current is 14 amperes.

Allowing for a field temperature of 65 °C, the resulting field voltage will be 154 volts. This value will be used as rated to determine the limiter and relay coordination settings.

OFF-LINE PERFORMANCE

The automatic voltage regulator was tuned by adjusting the rate feedback time constant (A4P) to 4.0 on its dial. The automatic regulator gain was set at 4.4, lead at 10.0, lag at 0.0. Figure 3 shows small signal step response of the closed-loop automatic voltage regulating system with the unit off line at rated voltage and speed. The 10- to 90-percent rise time of the terminal voltage is about 0.4 second and the overshoot is about 16 percent. The control system performance is well damped, with one overshoot and no apparent oscillation.

A Bode plot of the frequency response of the off-line automatic regulating system is shown in figure 4. The 3-decibel bandwidth is approximately 1.0 hertz and the resonant peak magnitude is approximately 1 decibel above the steady-state gain. These values indicate a moderate-speed, well-damped control system.

The minimum of the 90P [a-c (alternating-current) adjuster] was set at 90 percent of terminal voltage via the bias pot. The maximum of the 90P was set at 110 percent of terminal voltage via the range pot.

The minimum of the 70P [d-c (direct-current) adjuster] was set to produce 80 percent terminal voltage via the bias pot. The main field voltage (Efd) was 68 volts at this setting. The maximum of the 70P was set to 110 percent of field voltage at rated operation conditions and 35 °C (154 volts) via the range pot.

The manual regulator was tuned by adjusting the lag pot from full CCW (counterclockwise) to one-fourth turn CW (clockwise). The overshoot is about 8 percent. The 10- to 90-percent rise time of the field voltage is about 0.4 second. Figure 5 shows the small signal step response of the closed-loop manual voltage regulating system with the unit off line at rated voltage and speed. The control system performance is well damped, with one overshoot and no apparent oscillation.

ON-LINE PERFORMANCE

The automatic voltage regulator did not need to be re-tuned for on-line operation. Figure 6 shows the small signal step response of the closed-loop automatic voltage regulating system with the unit on line at full load and unity power factor. The 10- to 90-percent rise time of the terminal voltage is about 1.2 seconds. There is no overshoot. The control system performance is well damped, with no overshoot and no apparent oscillations. It is, unfortunately, quite slow.

A Bode plot of the frequency response of the on-line automatic regulating system is shown in figure 7. The 3-decibel bandwidth is approximately 0.45 hertz. The local mode resonant frequency is about 1.2 hertz.

POWER SYSTEM STABILIZER PERFORMANCE

Power system stabilizer lead time constants were set at 0.49 seconds (corner frequency of 0.32 hertz). Therefore, the dials T2 and T4 were set at 2.45.

Power system stabilizer lag time constants were set at 0.06 seconds (corner frequency of 2.8 hertz). Therefore, the dials T3 and T5 were set at 5.35.

The power system stabilizer gain was set at 0.6 on the dial which has the gain of 4 V/V (volt/volt). This provides a stabilizer gain of 4.8 per unit. The power system stabilizer Washout and Output limits were set at 6.0 on the dial which causes limiting at 5.4 volts. The Washout and Output time constant was set at 9.1 on the dial which set the time constant to about 30 seconds. The ceiling sensing delay was set at 3.0 on the dial which results in about a 10-second delay. The ceiling sensing positive and negative thresholds were set at 10 on the dial which is about 10 volts.

Since the automatic voltage regulator control system was slow and well damped, the power system stabilizer did not contribute significant damping to the local mode oscillation. Therefore, the machine terminal frequency was selected as the power system stabilizer input instead of internal frequency. This allows more gain for system oscillation damping. This was accomplished by leaving the CT shorting switch (at the power system stabilizer input panel) open and placing a jumper wire across the L1X reactor transformer secondary.

Figure 8 shows the local mode oscillation of the unit without the power system stabilizer. Figure 9 shows the local mode oscillation of the unit with the power system stabilizer in service. Damping was slightly increased with the power system stabilizer in service.

Figure 10 shows the Bode plot of the frequency response of the unit with the power system stabilizer-compensated-open-loop. The phase at the local mode frequency of 1.2 hertz is about -75°.

Figure 11 shows the Bode plot of the frequency response of the unit with power system stabilizer-compensated-closed-loop. At local mode frequency, the magnitude is lower than the on-line frequency response (without power system stabilizer). This indicates some local mode damping.

AUTOMATIC LIMITERS

The Hoover regulators are equipped with V/Hz (volts per hertz) limiters, URAL (underreactive ampere limiters), and maximum excitation limiters. These act into the a-c regulator and take control if certain conditions are present. They do not function if the regulator is in d-c (manual) regulator mode.

The V/Hz limiter limits the ratio of terminal voltage and speed. It monitors the terminal voltage to determine the speed (frequency) of the unit, and it converts the frequency into voltage. This reference voltage is fed into the a-c regulator card so the ratio of terminal voltage and speed is maintained by the regulator.

The V/Hz limiter was set at a ratio of 2.02. Limiter performance was tested by increasing the 90P to maximum and then lowering the speed. Data were taken down to 48 hertz. The V/Hz calibration was set with 6 volts at 60 hertz. It varied 1 volt per 10 hertz. The V/Hz annunciated when the speed was lowered to 48 hertz. The V/Hz limiter maintained a ratio of 2.02 V/Hz (±0.02) at all values of speed. Table 1 shows the test results of the V/Hz limiter board.

Table 1. - V/Hz limiter data.

PT (V)	Speed (Hz)	Ratio
121	60	2.017
111.2	55	2.022
102.85	50.4	2.04
97.44	48.1	2.026

The URAL prevents the generator from operating too far into the underexcited region. It monitors the three-phase terminal voltage (line to neutral) and the line current of phase B to determine the underexcited megavars of the machine. The URAL board produces a signal proportional to the underexcited megavars which exceeds an amount determined by the adjustments on this board. Table 2 lists several points at which the URAL becomes active. The URAL does not annunciate.

Table 2. - URAL limiter data.

MW	Mvar
0	-62
28	-58
52	-54
78	-45
104	-32
127	-10

The maximum excitation limiter has two functions. First (primary current limiter), it provides a fixed instantaneous exciter field current limit. This allows a high level (typically 150 percent) of excitation for a short time. Second (maximum excitation limiter recalibration), it provides an inverse time characteristic device (J2CB). After the operation of this device, the excitation is reduced to the rated value.

The primary current limiter limits the field voltage via the A1P potentiometer dial setting. The current limiter circuit monitors the SCR (silicon controlled rectifier) bridge current to determine if the bridge current exceeds the limit set by A1P. The A1P wiper voltage is fed into the regulator. The limiter takes over whenever the wiper voltage of A1P is -7.5 volts or less.

The primary current limiter A1P was set at 4.0 on the dial. This limited the field voltage at 244 volts on line and 269 volts during transient startup conditions. This allows approximately 155 percent of field voltage at rated load for a short time. This is close to the ideal value of 150 percent.

The maximum excitation limiter recalibration uses the same circuit as the primary current limiter. Potentiometer J1P is placed in series with A1P whenever the maximum excitation limiter recalibration is in service.

The maximum excitation limiter recalibration (J1P) was set at 0.0 on the dial. This limited the field voltage at 156 volts on line and 178 volts during transient startup conditions. The ideal value is field voltage at rated load condition which is 154 volts. The transient startup condition values are higher since there is no load current out of the exciter during this type of test.

Table 3 shows the settings of A1P and J1P limiters and their test results. Figure 15 shows the coordination of the URAL and the maximum excitation limiter with the capability curve.

Table 3. - Current limiter and recalibration settings.

Potentiometer	Dial setting	On-line	Transient startup
A1P	4.0 dial	Efd = 244 V	Efd = 269 V
J1P	0.0 dial	Efd = 156 V	Efd = 178 V

RELAYING COORDINATION

Speed switch 13A was set to close the field breaker via relay 13AY at 94 percent of rated speed and open it via relay 13AX at 89 percent.

The V/Hz relay causes an 86 lockout whenever the ratio of terminal voltage and speed exceeds its setting for a period longer than its time delay. The V/Hz relay was set at a ratio of 2.1 and 15 seconds delay. The relay was tested at rated voltage by lowering the speed. The relay picked up at 52.3 hertz. The trip wire was lifted at T50 so the relay would not cause a lockout. In order to protect the generator and the transformer, the field breaker was manually opened when the relay alarmed. The relay did not operate with the V/Hz limiter in service. This test indicated proper operation.

The overexcitation relay 59E was set at 135 percent of rated field, which is 209 volts with target up, and its time delay relay (J2KX/TD) was set at 40 seconds. The high overexcitation relay 59E/H was set at 20 volts above the off-line ceiling value. This was 296 volts with target down.

The maximum excitation limit inverse time board (J2CB) was set at 159 volts (5 volts above rated field voltage). This board drives relay J1K, which activates the maximum excitation limiter recalibration (potentiometer J1P).

The overexcitation protection inverse time board (J1CB) was set at 164 volts (10 volts above rated field voltage). This board drives relay J2K which transfers to manual regulator.

Refer to figure 14 for the main field winding protection coordination diagram.

Table 4. - Relay settings.

Relay	Setting	Time delay
59E	Efd = 209 V (target up)	40 seconds
59E/H	Efd = 296 V (target up)	None
J2CB	Efd = 159 V	Inverse time
J1CB	Efd = 164 V	Inverse time
V/Hz	Ratio of 2.1	15 seconds
Speed switch	13AY closes at 94%	None
	13AX opens at 89%	None

STARTUP PERFORMANCE

A normal start in a-c regulator mode caused the following: 59E/H did not pick up; and 59E picked up, but its time delay J2KX/TD blocked further action because it did not time out. Field voltage was limited at 272 volts (A1P 4.0 dial). The terminal voltage had a 2-percent overshoot. See figure 12.

In order to test the high overexcitation relay (59 E/H), A1P was adjusted to 5.0 dial and the trip of 59E/H (J4KX) was lifted at T56. The 59E/H then picked up at Efd = 300 volts; Ibr (SCR bridge current) = 34 amperes. A1P was reset to 4.0 dial (proper setting).

LOAD REJECTION PERFORMANCE

Speed and voltage recovered to normal values after the load rejections. The rated load rejection is shown in figure 13. Overvoltage and overspeed data for the load rejections are shown in table 5.

Table 5. - Load rejection data.

Load	Overspeed (%)	Prerejection voltage (%)	Overvoltage (%)
27 MW ; 0.0 Mvar	104.67	101.8	102.3
52 MW ; 0.0 Mvar	110.7	101.9	103.1
78 MW ; 0.0 Mvar	118.3	102	104.1
102 MW ; 0.0 Mvar	123.3	101.4	104.9
127 MW ; 0.0 Mvar	133	100.4	107.1
130 MW ; 29.5 Mvar	134.7	103.9	115.5

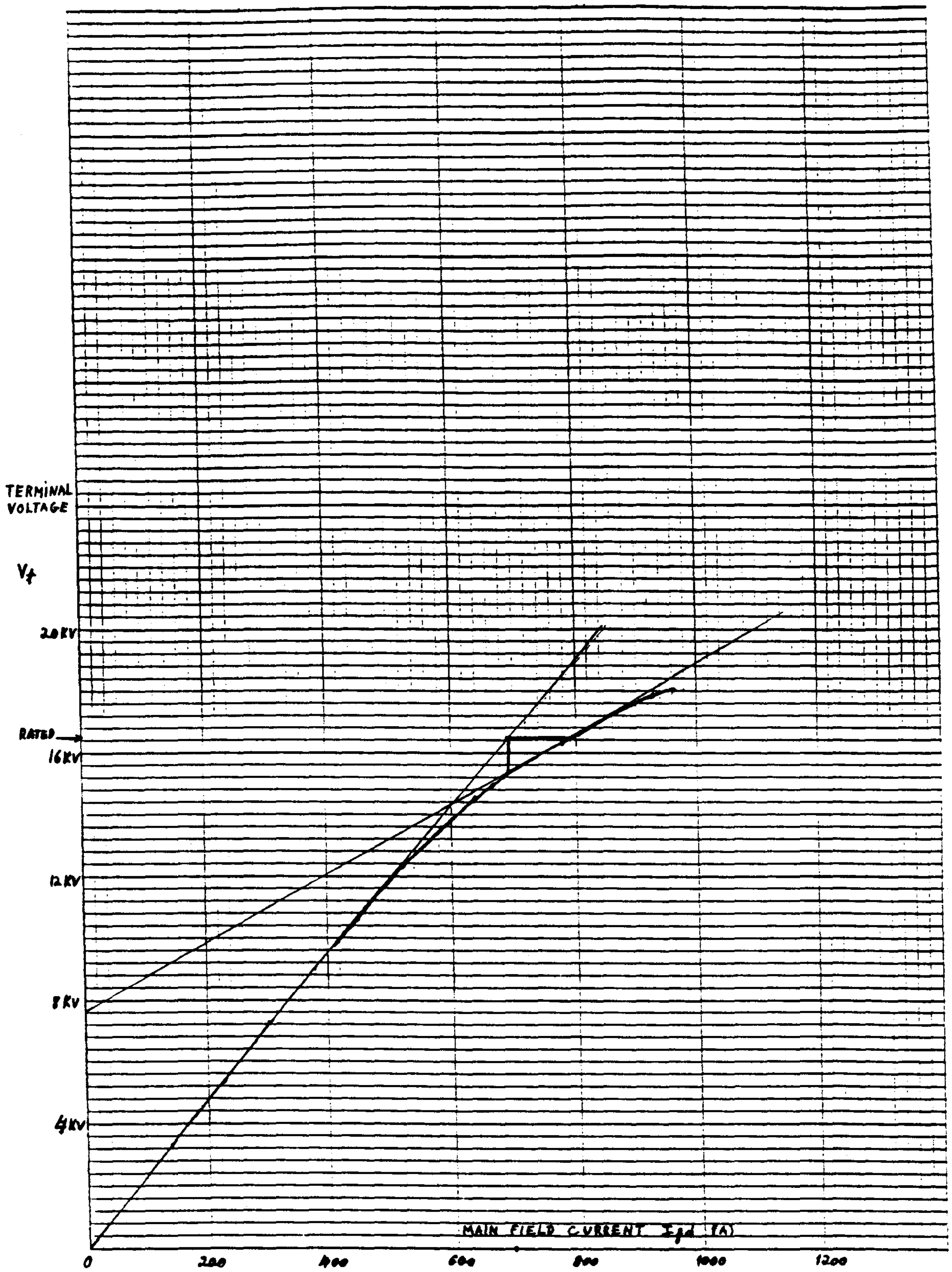


Figure 1. - Generator saturation curve.

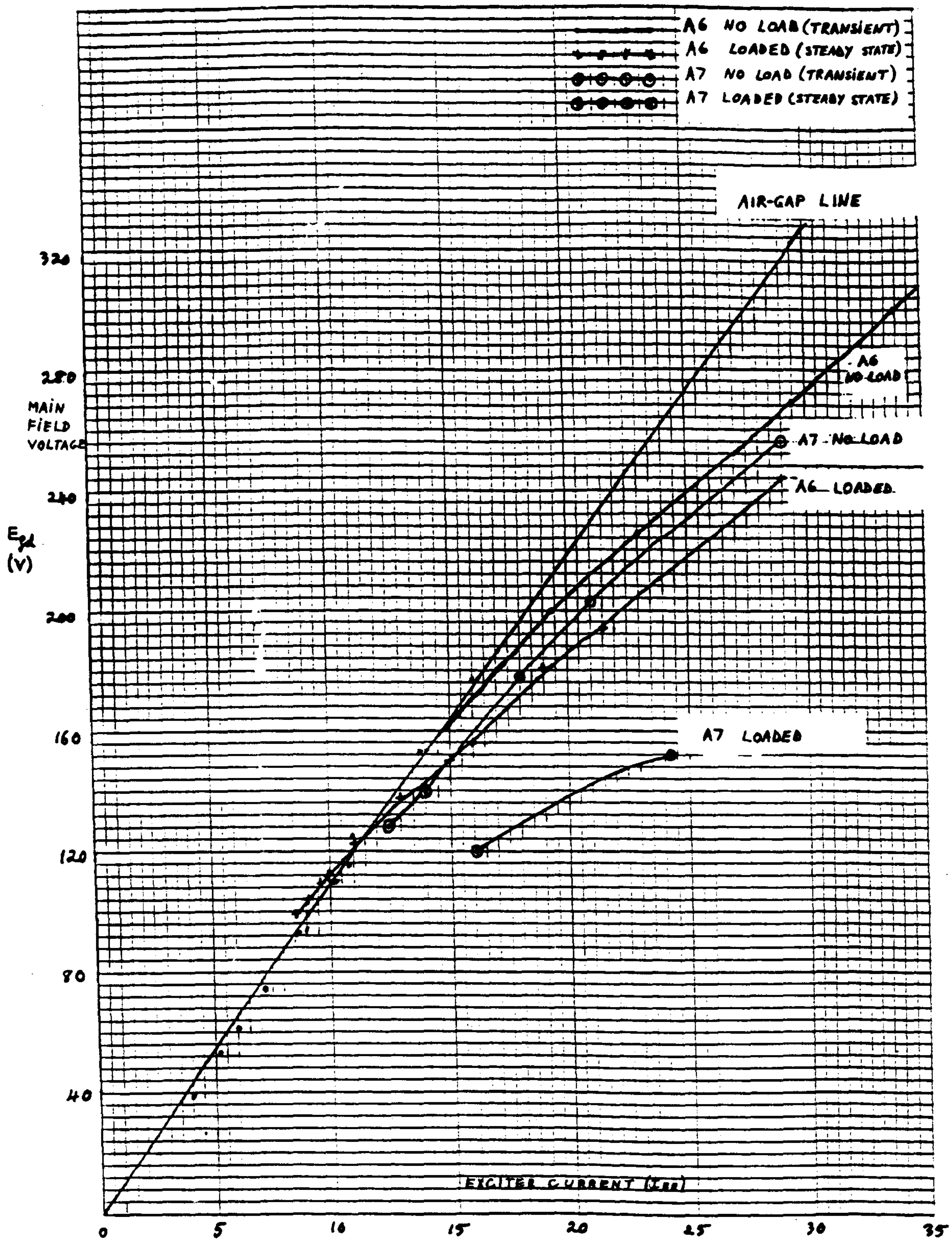


Figure 2. - Exciter saturation curve.

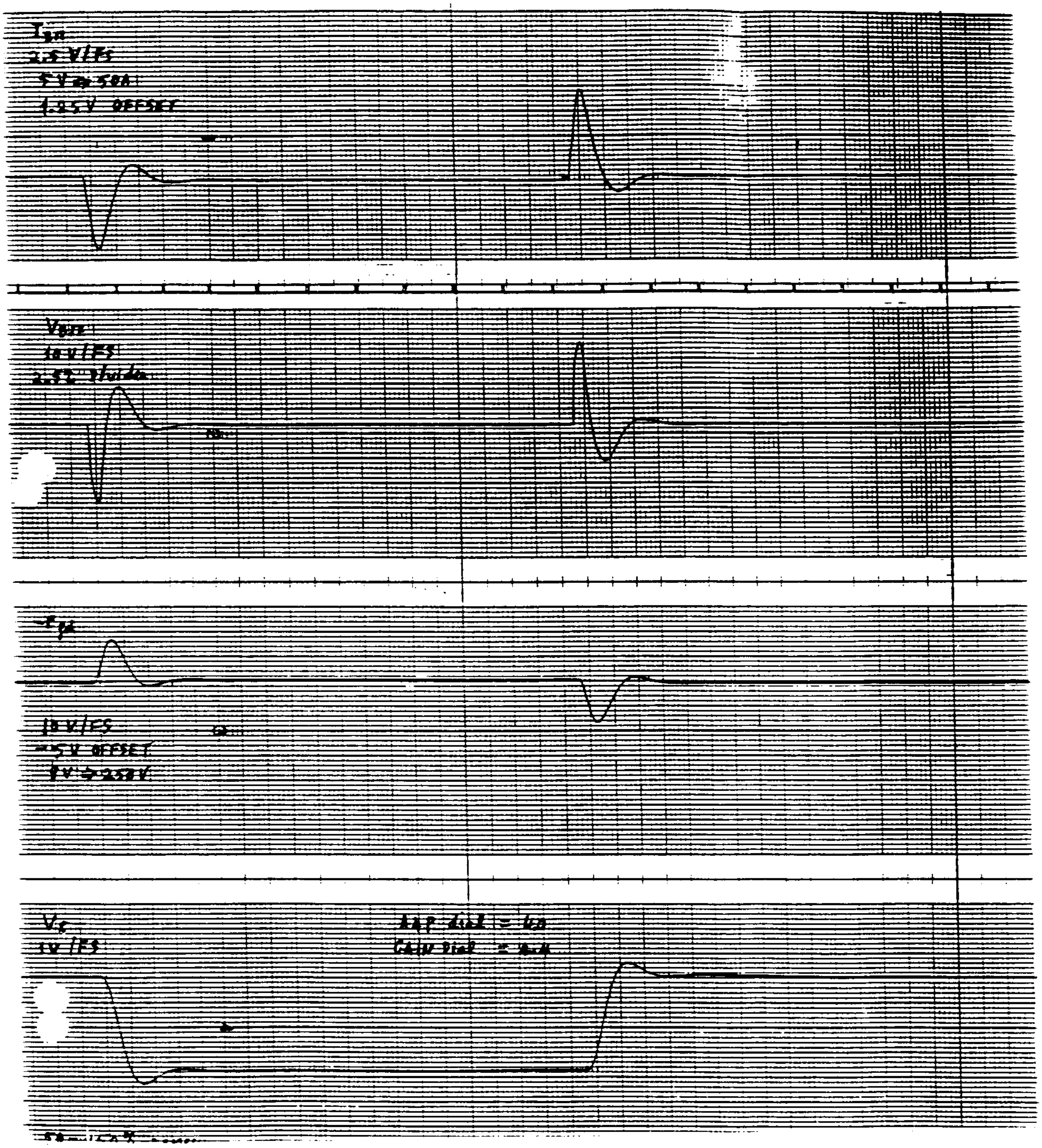


Figure 3. - Small signal step response of off-line system (a-c regulator).

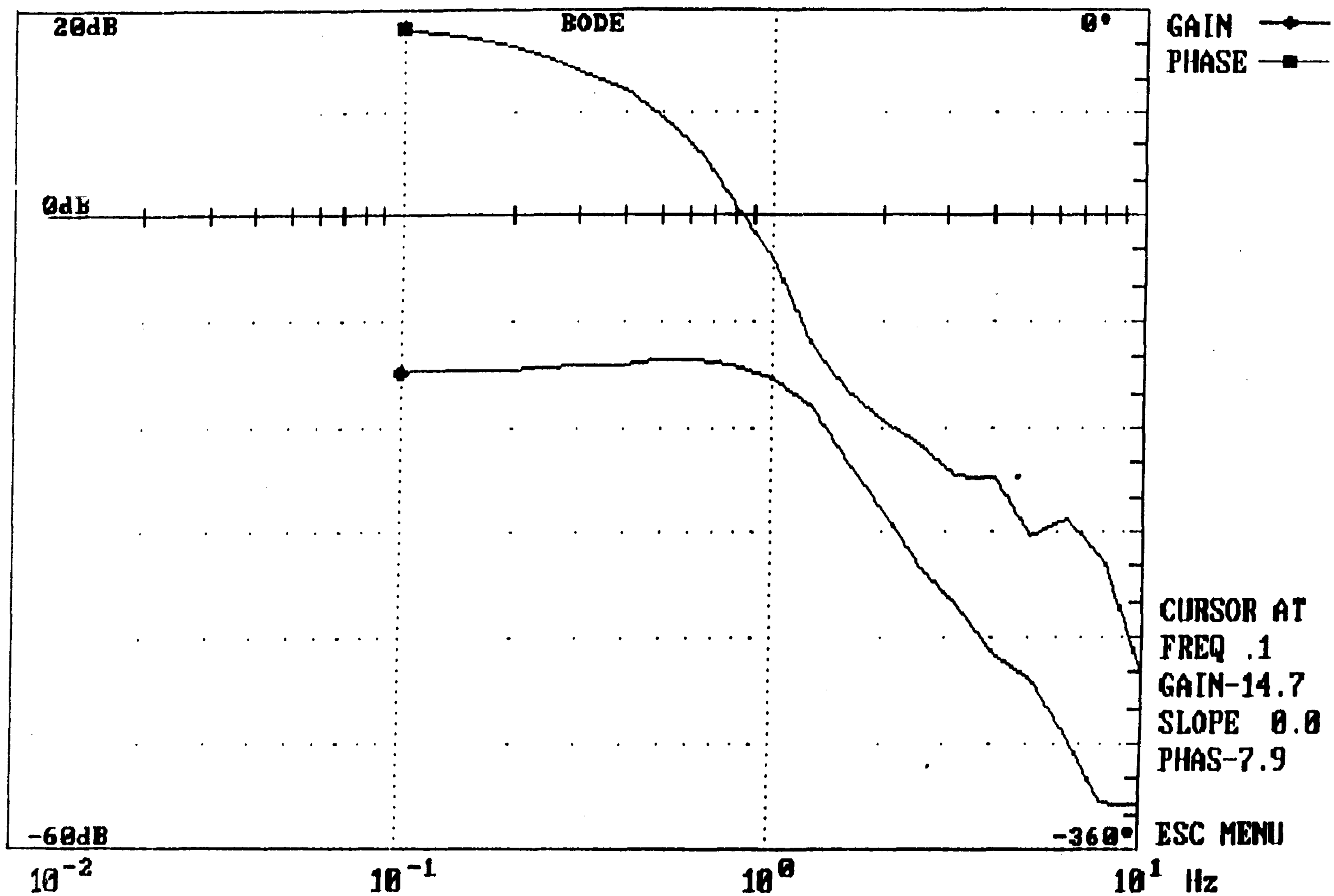


Figure 4. - Bode plot of off-line system.

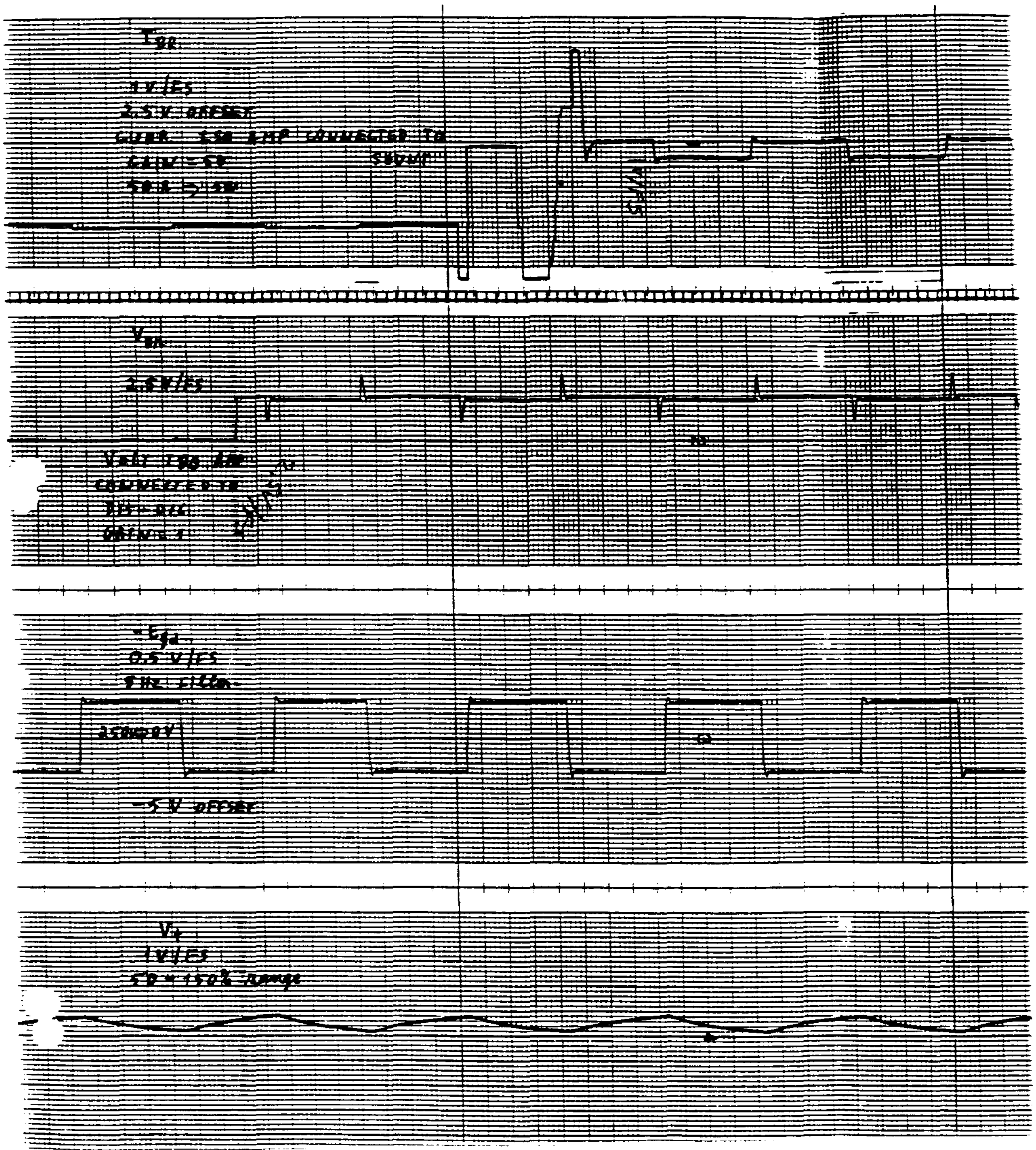


Figure 5. - Small signal step response of off-line system (d-c regulator).

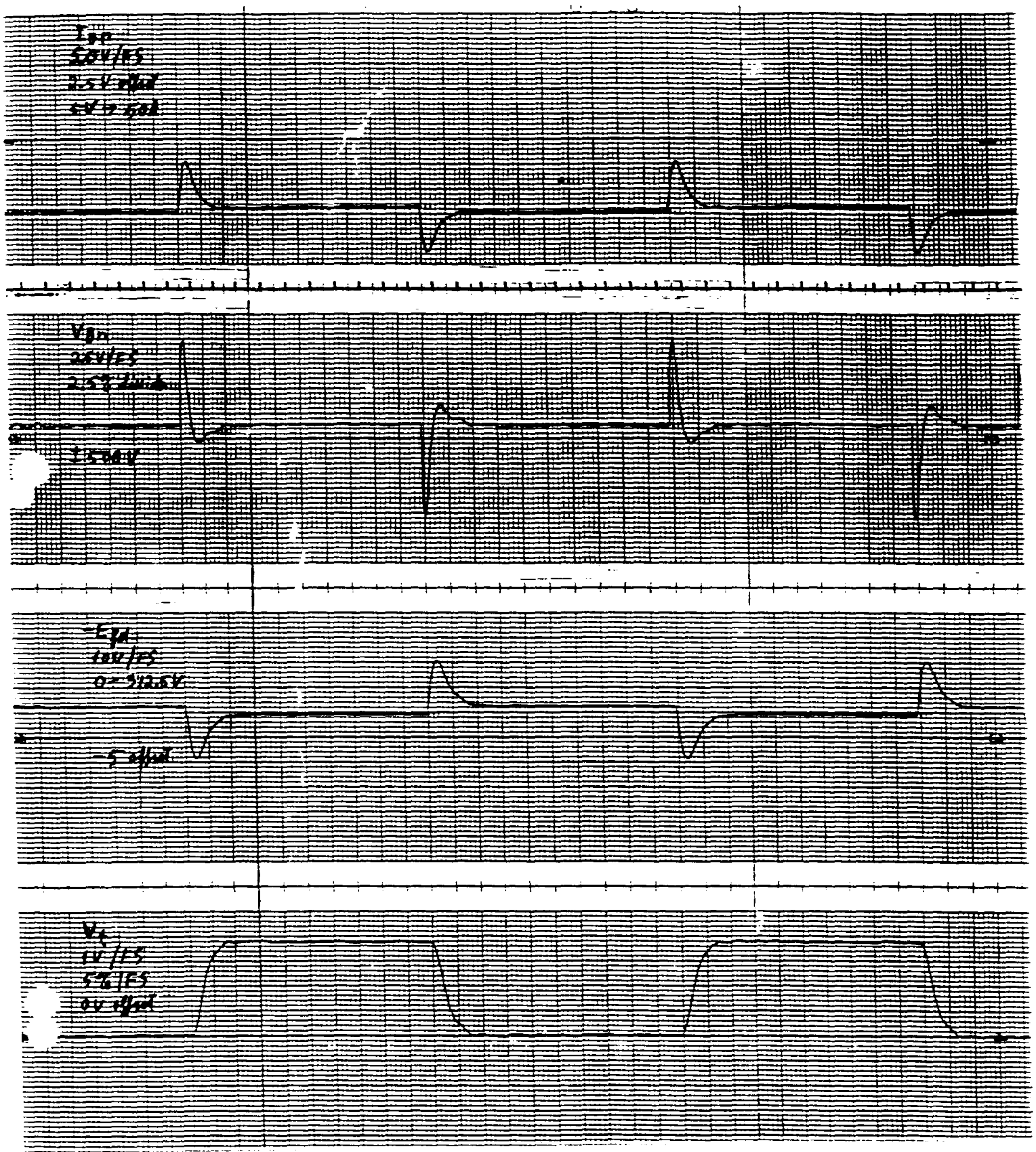


Figure 6. - Small signal step response of on-line system.

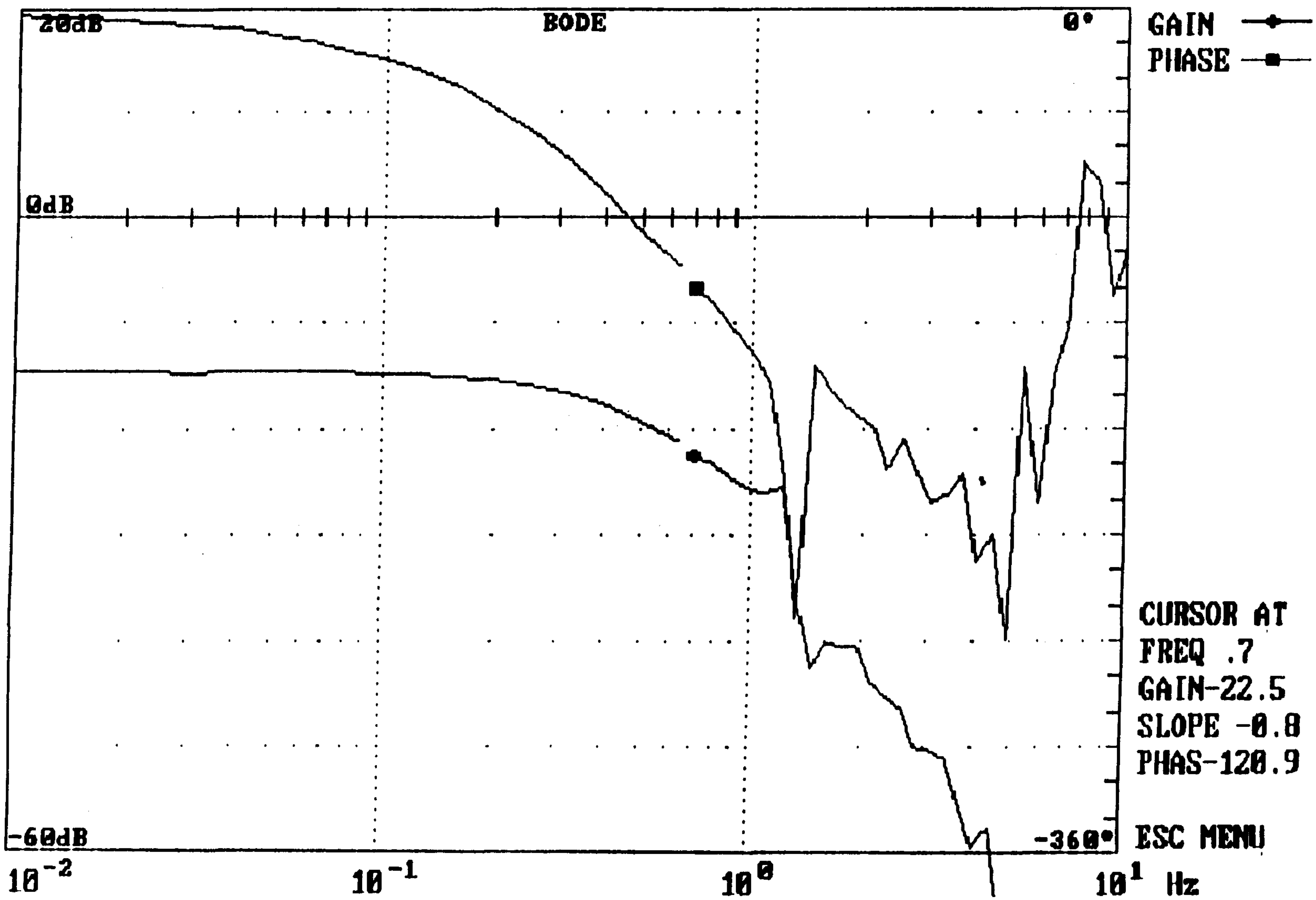


Figure 7. - Bode plot of on-line system.

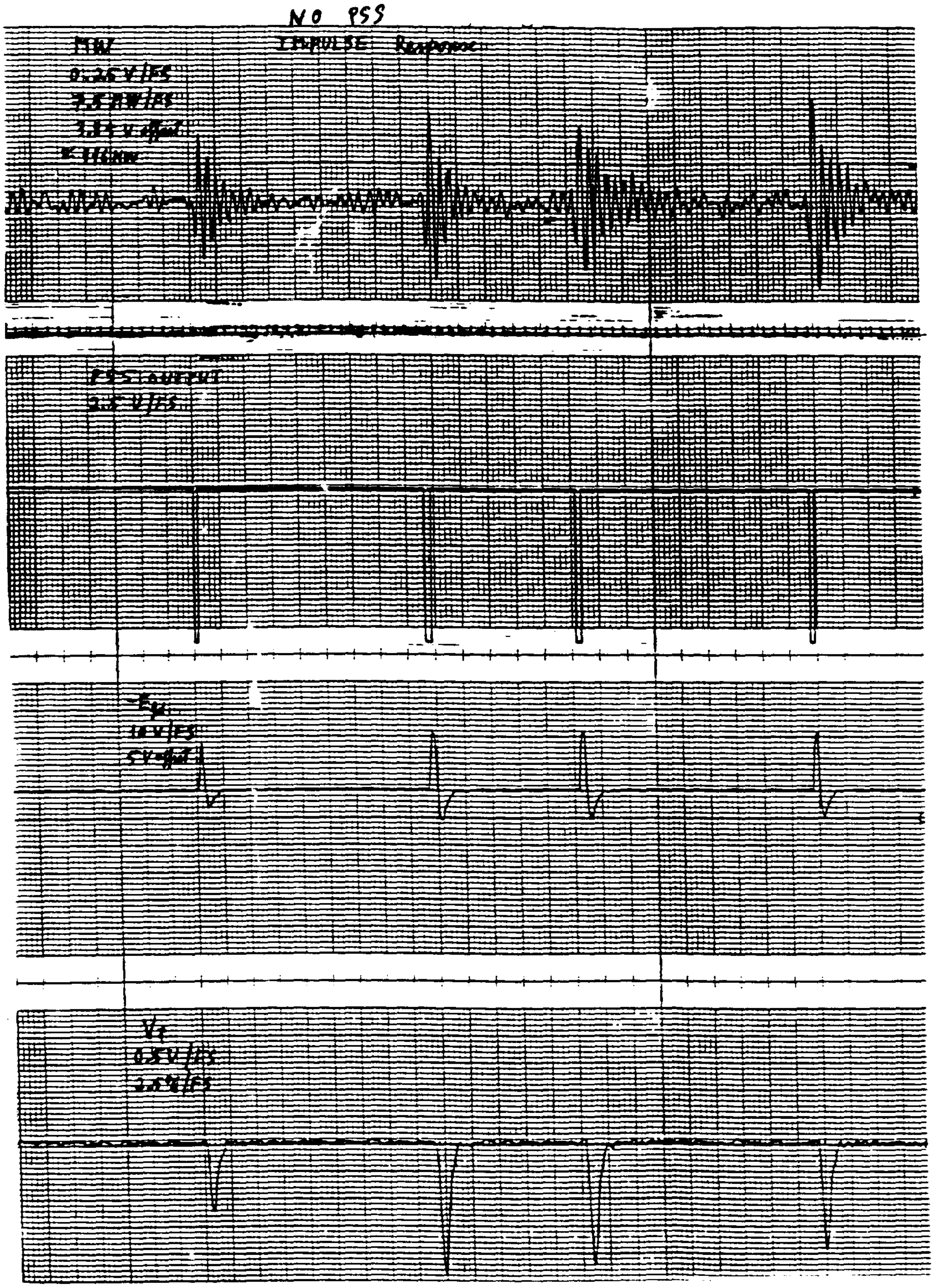


Figure 8. - Local mode oscillation without power system stabilizer.

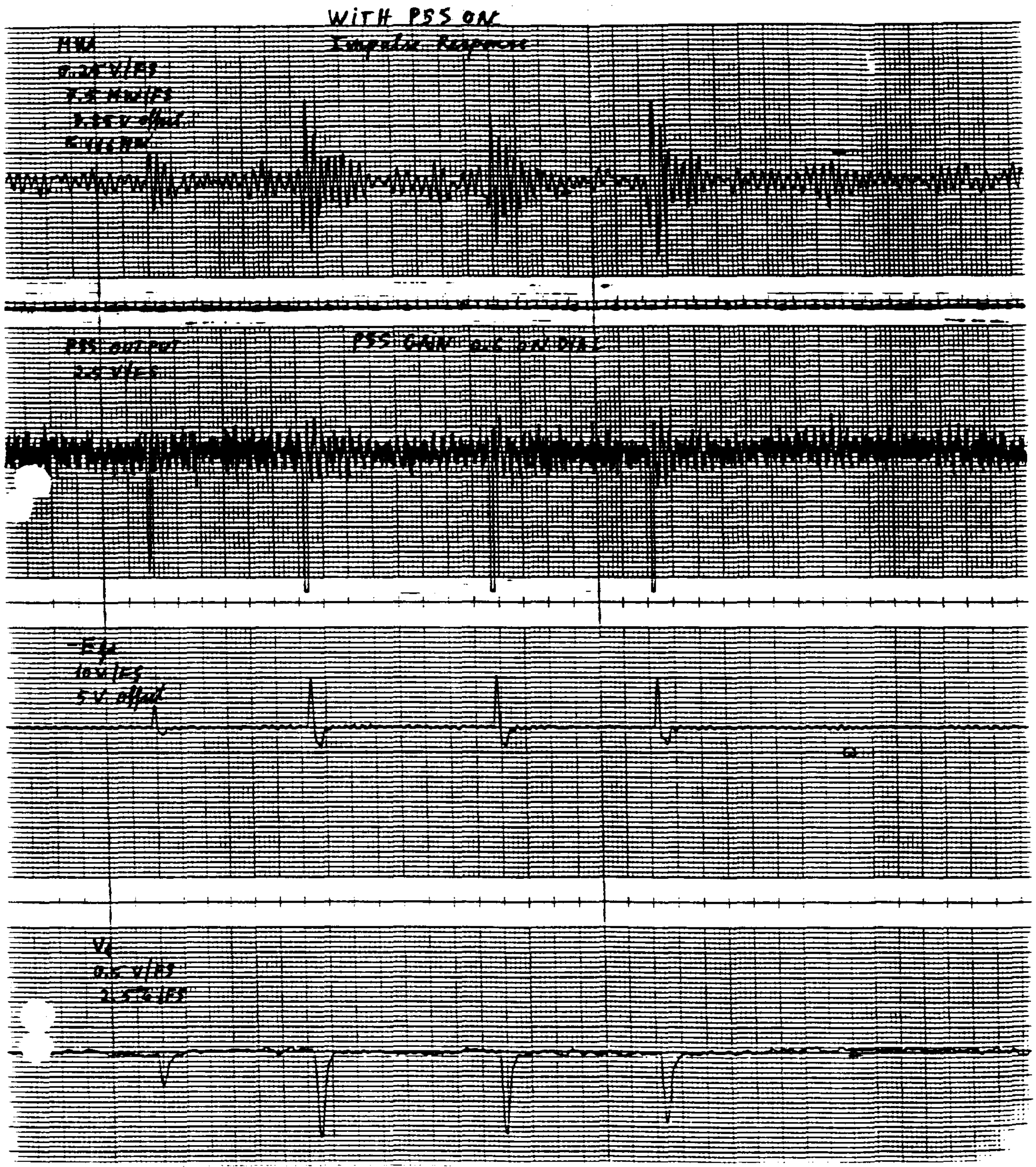


Figure 9. - Local mode oscillation with power system stabilizer.

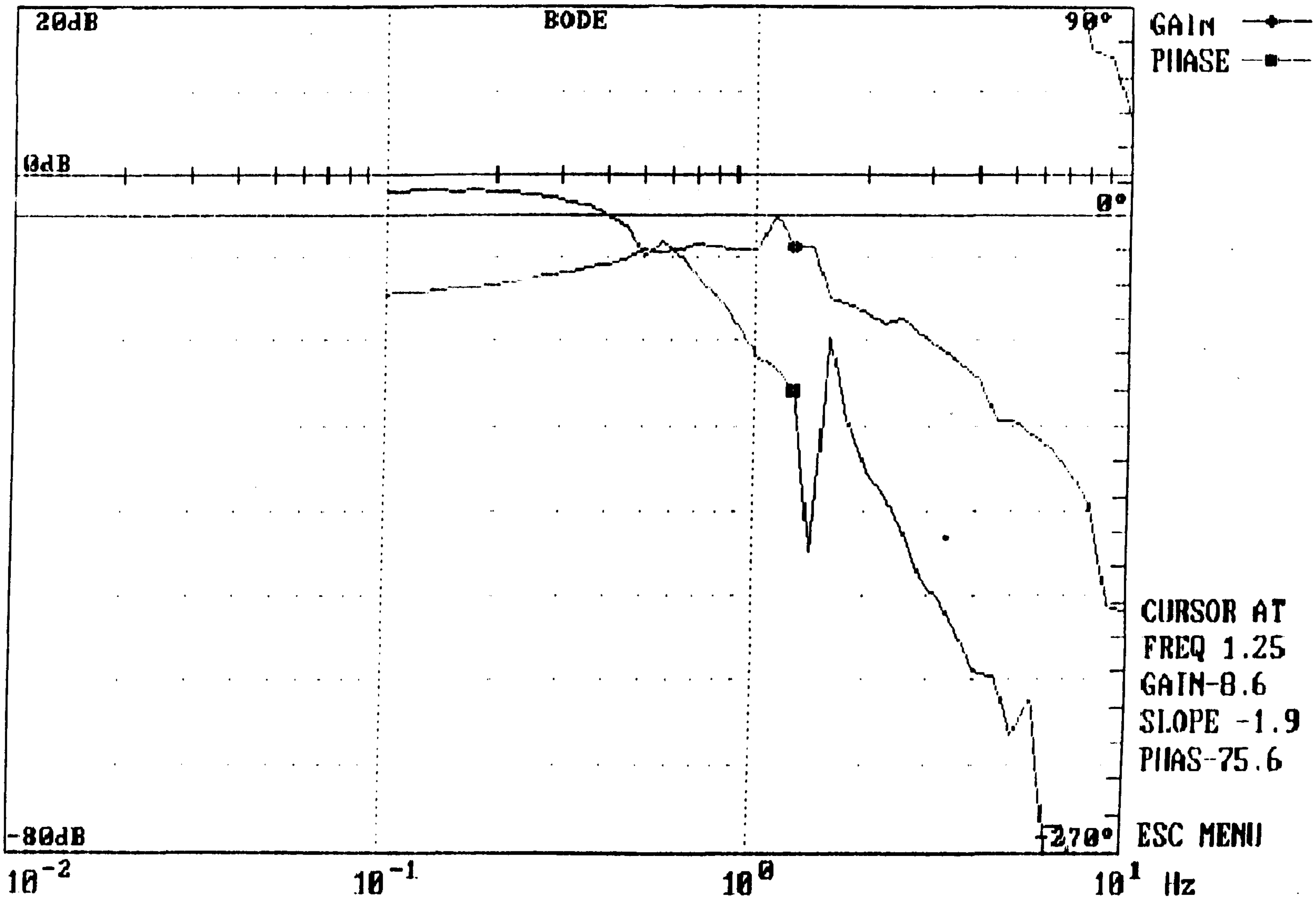


Figure 10. - Bode plot of frequency response of unit with power system stabilizer-compensated-open-loop.

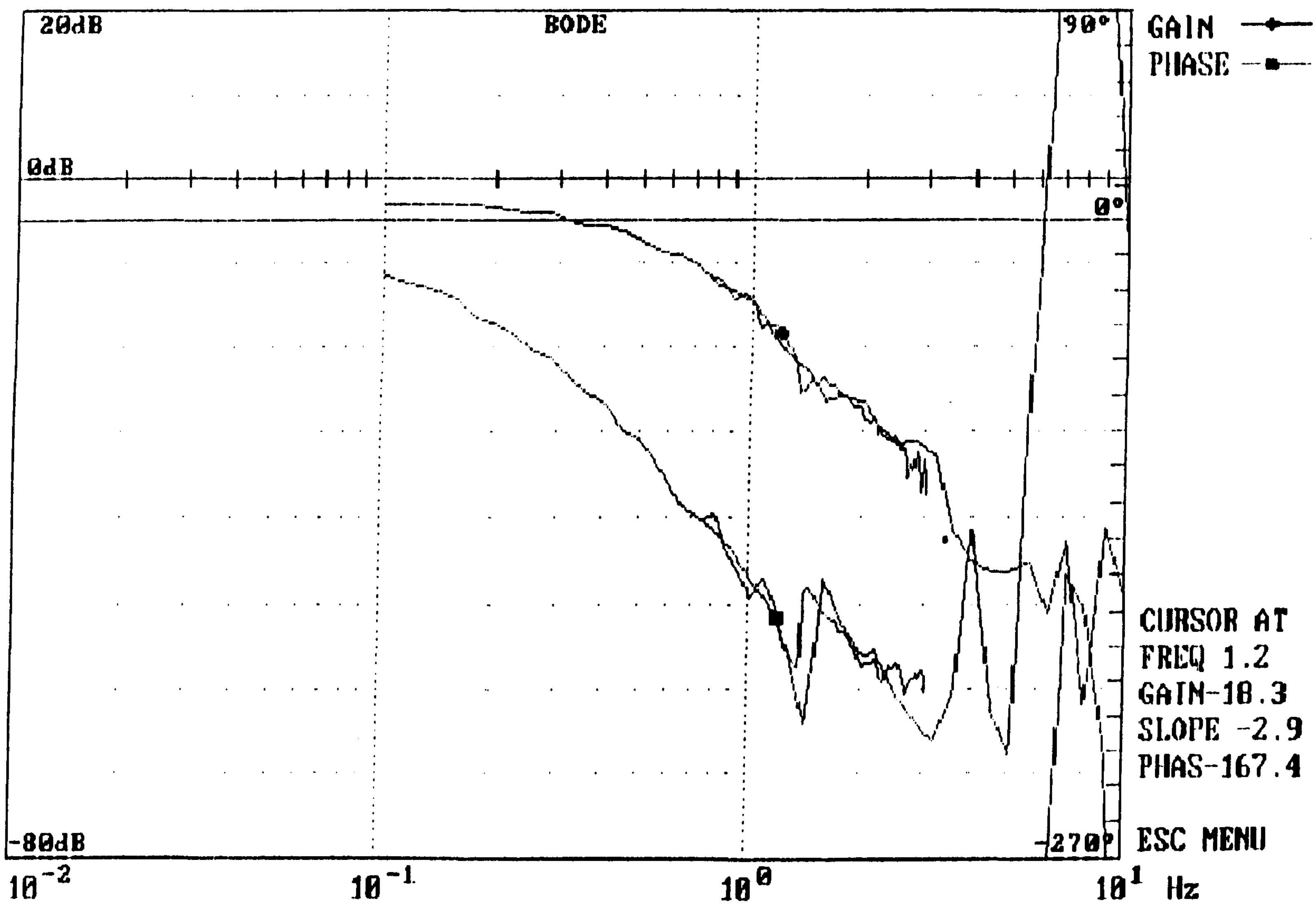


Figure 11. - Bode plot of frequency response of unit with power system stabilizer-compensated-closed-loop.

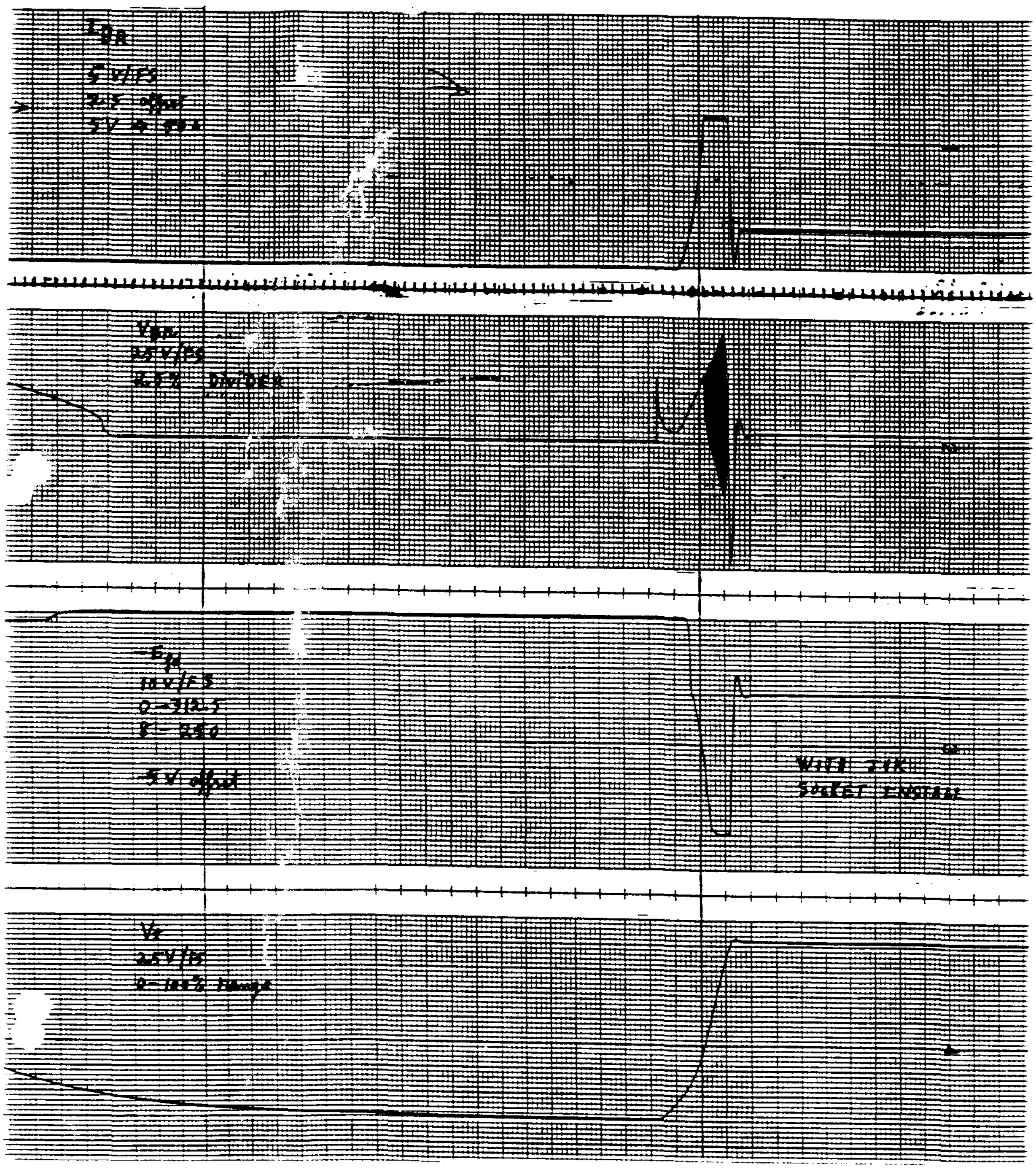


Figure 12. - Automatic voltage buildup in a-c regulator mode.

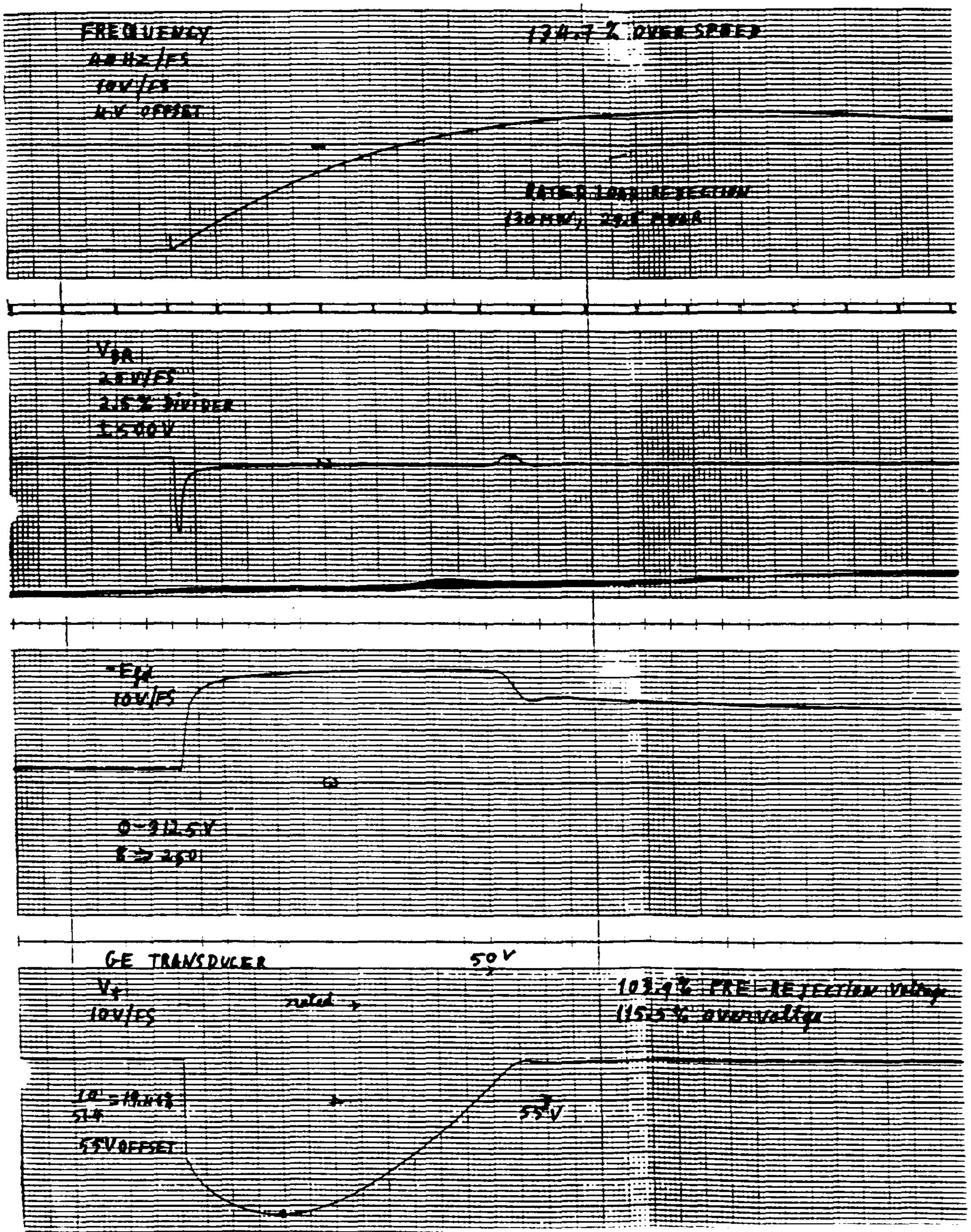


Figure 13. - Rated load rejection.

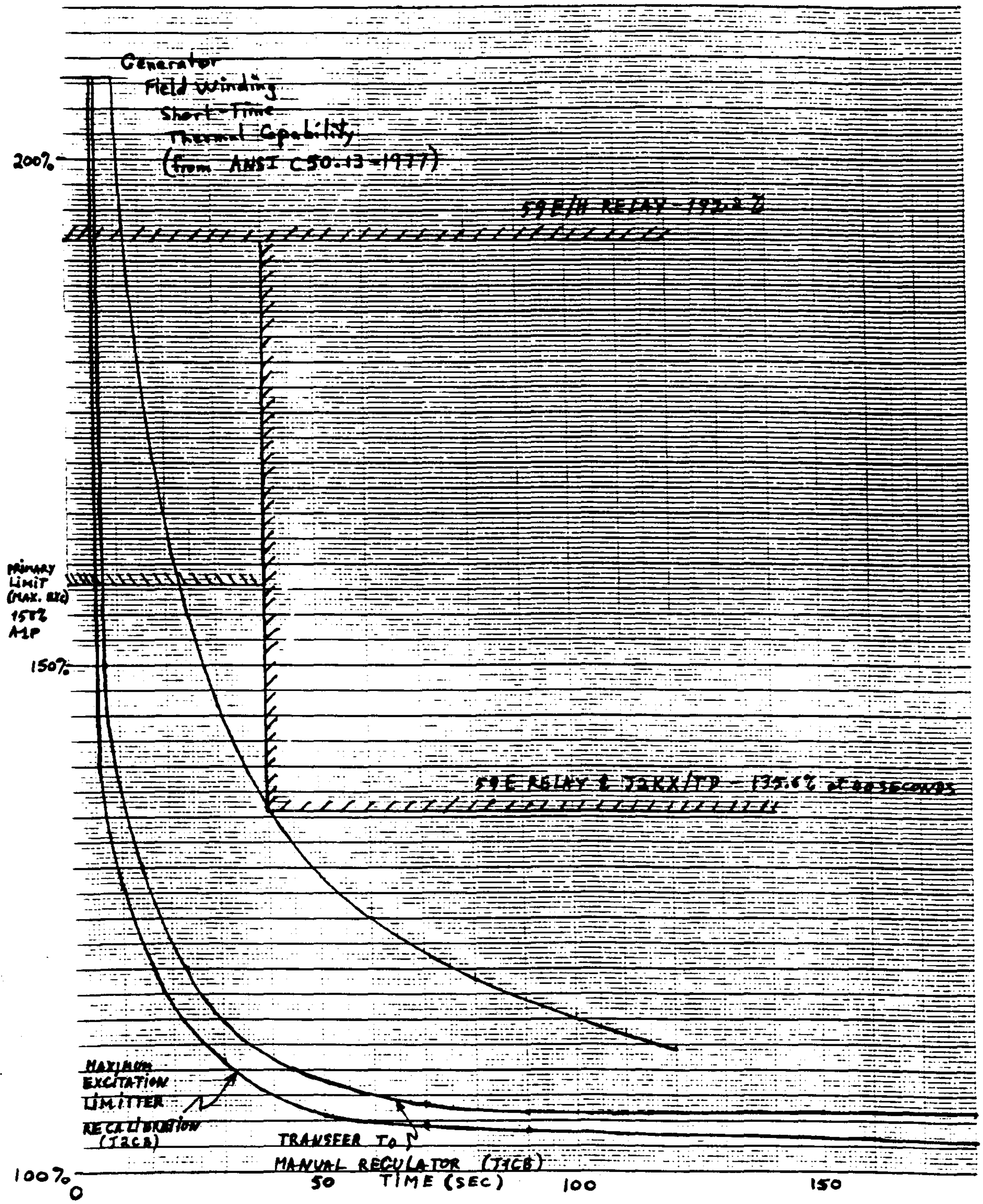


Figure 14. - Main field winding protection coordination diagram.

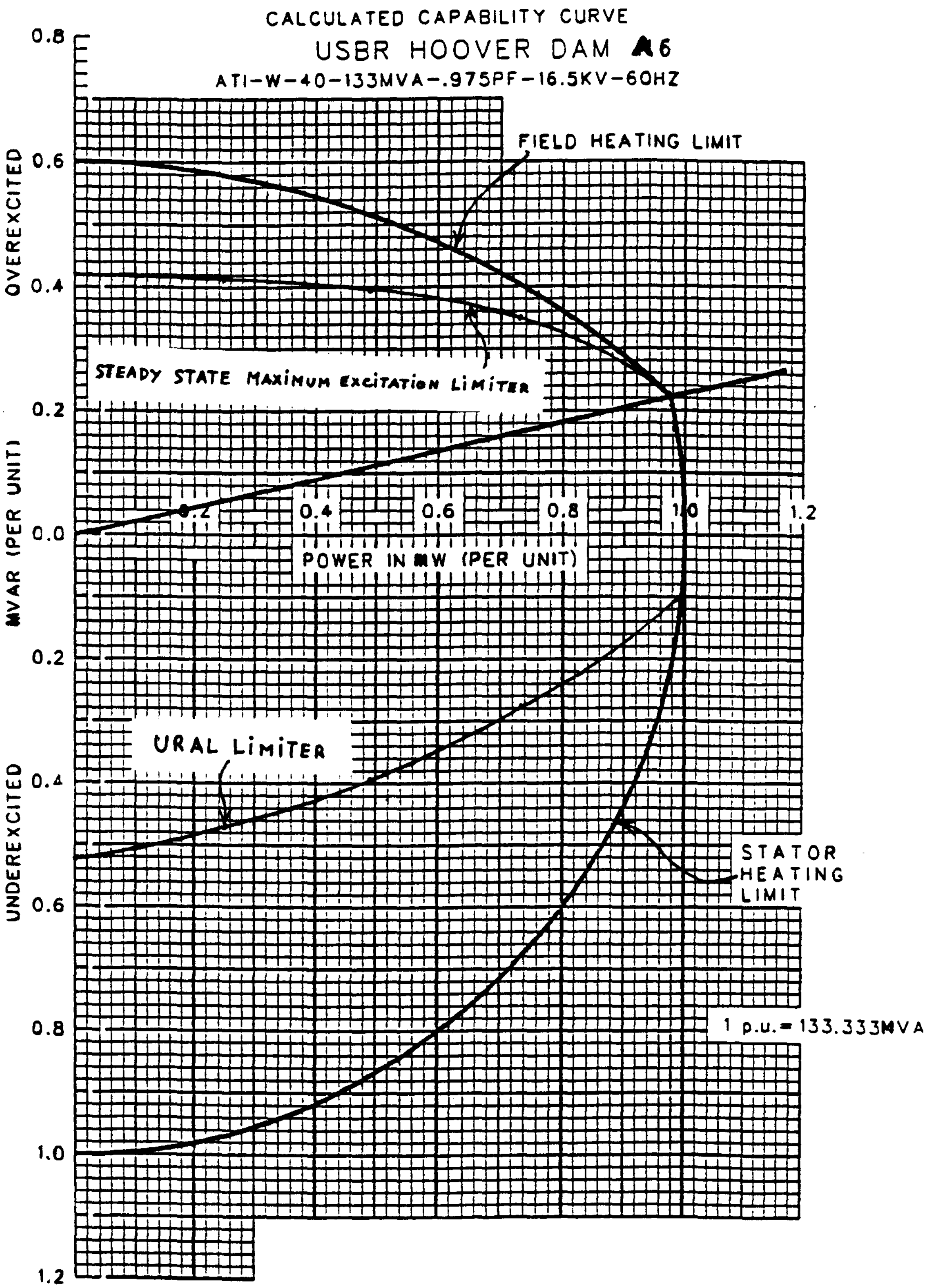


Figure 15. - Generator capability curve.

APPENDIX A

Special Conditions

The following special conditions were found to be useful during the tests. The tests were begun with all of these special conditions in force.

- Excitation supply voltage was obtained from the three-phase test transformer source connected to terminals 111, 112, and 113.
- Field flashing was disabled by lifting and taping K38 and K41.
- Preset positioning of the 70 and 90 adjusters was disabled at contacts 7, 8, 11, and 12 of 41R1 relay (located in the field breaker enclosure).
- Transfer to automatic regulator was blocked by lifting wire ERT at T108.
- Field breaker close by 13AX via 13AY was disabled by lifting EBC2 at T52.
- Bridge voltage was fed back to field voltage transducer instead of the field voltage (for initial voltage buildup).
- Ceiling voltage was limited to minimum value by pulling the socket of the J1K relay to activate J1P current limiter action.
- All of the following cards were pulled: V/Hz, current compensation, URAL, a-c regulator, and every card from power system stabilizer rack.

APPENDIX B

Test Connections

The test set frequency and voltage transducers were connected to the PT voltage on the knife switch in the relay cabinet.

The exciter field current was measured at the exciter field shunt in the relay cabinet. The exciter field voltage was measured at terminal D15-D16 in the relay cabinet.

The main field voltage was measured at the General Electric's transducer in the regulator cabinet.

The megawatts were measured from a transducer which was connected to the PT and CT switches at the control board.

The input signal was connected through the IN1 jack of the washout and output card in the power system stabilizer rack.

The input signal for d-c regulator step response was connected at terminals HM19-HM20.

APPENDIX C

Parameter Record

y: ______________________ Project: ______________________

ite: ______________________ Apparatus: ______________________

eneral Data: ______________________

PARAMETER	AS FOUND	EXPERIMENTAL VALUES	AS LEFT	NOTES
A4P	2.0		4.0	
A1P	0.0		4.0	
A2P	0.0		0.0	
3 cap & A6R A7R	Exists		Exist	
V/HZ card GAIN	(↗)		SAME	
" " LF SW	(↖)		SAME	
Impedance Compensator R	0.0		0.0	
" " X	0.0		0.0	
URAL R1 CNTR	(−)		SAME	
" R2 RADUS	(↗)		"	
" R3 GAIN	(−)		"	
" R4 VCAL	(1)		"	
" R5 ICAL	(1)		"	

': ______________________ Project: ______________________

ite: ______________________ Apparatus: ______________________

eneral Data: ____

PARAMETER	AS FOUND	EXPERIMENTAL VALUES	AS LEFT	NOTES
3 channels Comparator CH 1 SET POINT	⦸		SAME	
" " " CH 1 Time Delay	⊖		"	
" " " CH 2 SET POINT	⦶		"	
" " " CH 2 TIME Delay	⊘		"	
" " " CH 3 SET POINT	⊖		"	
" " " CH 3 TIME Delay	⦶		"	
DC Regulator lag	⦸		⊘	
" " lead	⊖		SAME	
" " GAIN	⊖		SAME	
" " BIAS	⊖		⦸	
" " RANGE	⊖		⦶	
AC Regulator lead	10.0		SAME	
" " lag	0.0		SAME	
" " GAIN	4.4		SAME	
" " BIAS	⦶		⊖	
" " range	⦸		⊖	

y:

te:

neral Data:

Project:

Apparatus:

PARAMETER	AS FOUND	EXPERIMENTAL VALUES	AS LEFT	NOTES
60MR AUTO TRACK RAISE	14.0		SAME	
60ML AUTO TRACK Lower	14.0		SAME	
J1P current Limit Recalibrate	0.0		SAME	

/: ____________

ite: ____________

neral Data: ____________

Project: ____________

Apparatus: ____________

PARAMETER	AS FOUND	EXPERIMENTAL VALUES	AS LEFT	NOTES
PSS SIGNAL COND. TCT2 V			0.0	
TCT2 F			2.45	
TCT3			5.35	
TCT4			2.45	
TCT5			5.35	
PSS Washout output NEG. LIMIT			6.0	
POS - LIMIT			6.0	
GAIN K			0.6	
TCT1			9.1	
PSS ceiling SENSING DELAY			3.0	
POS LIMIT			10.0	
NEG LIMIT			10.0	

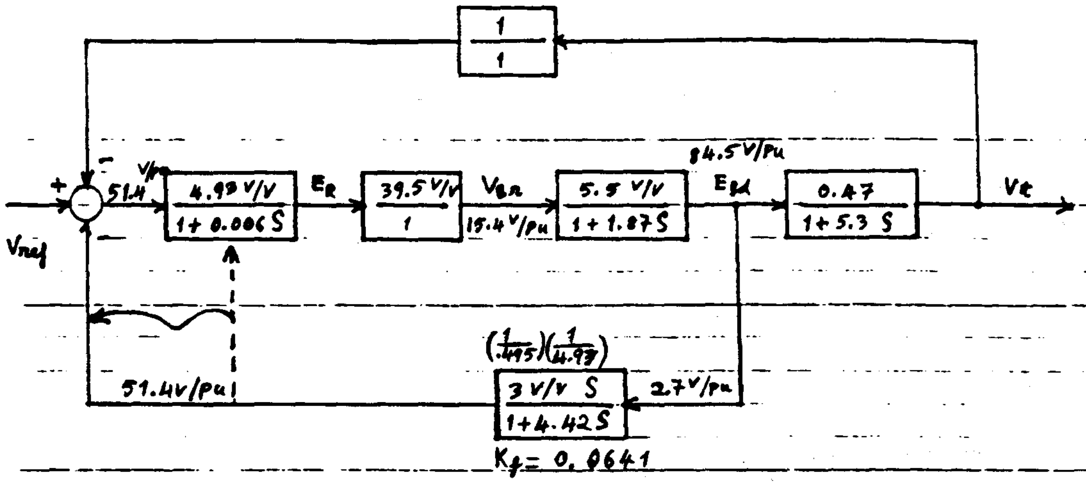
APPENDIX D

Computer Model Representation

7-1654 (7-73)
Bureau of Reclamation

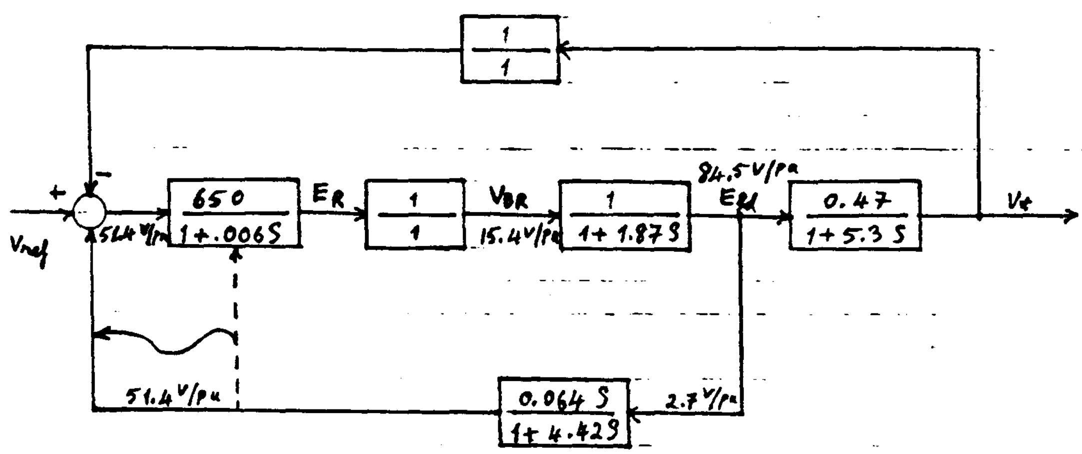
COMPUTATION SHEET

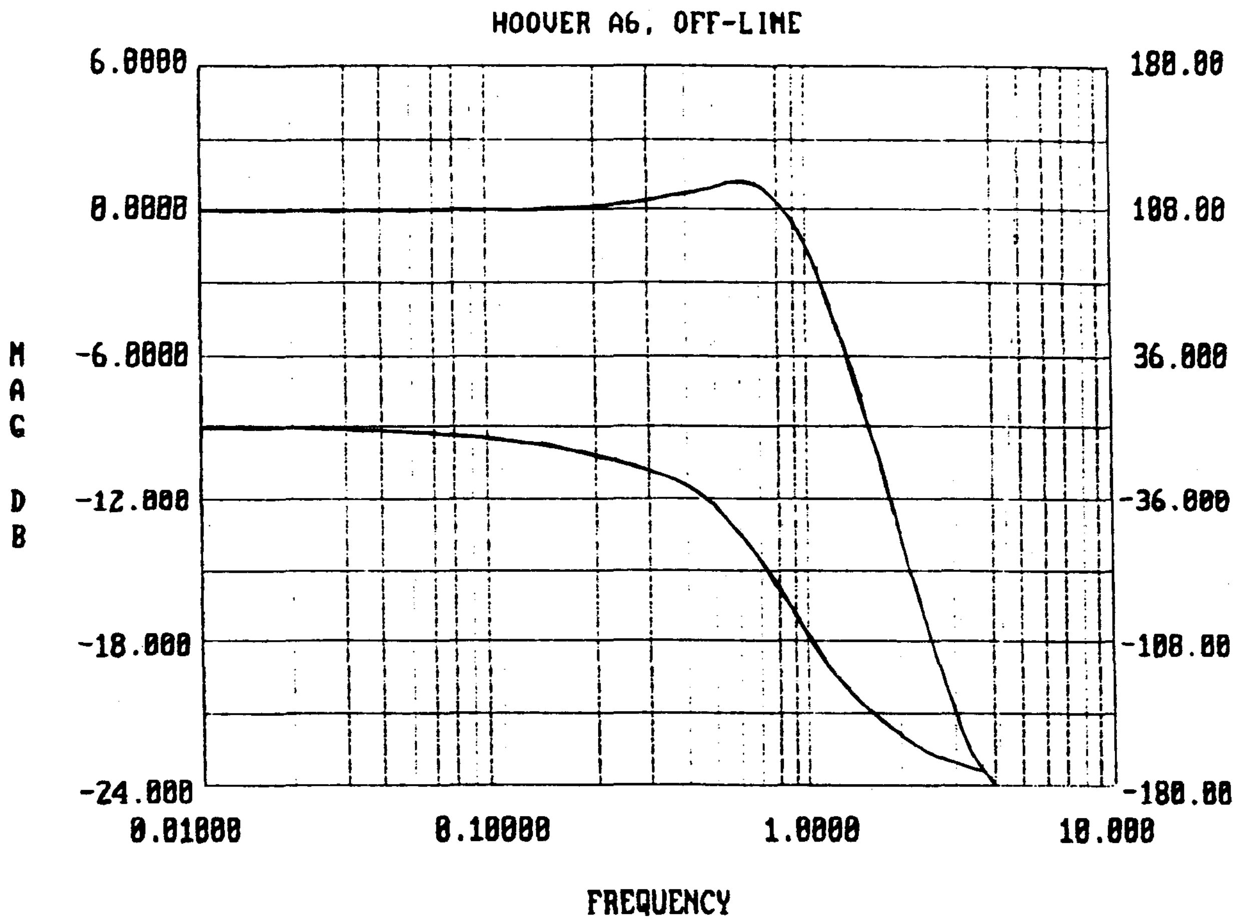
BY HV	DATE	PROJECT Hoover	SHEET ___ OF ___
CHKD BY	DATE	FEATURE A6	
DETAILS A6, OFF-LINE EXCITATION MODEL			

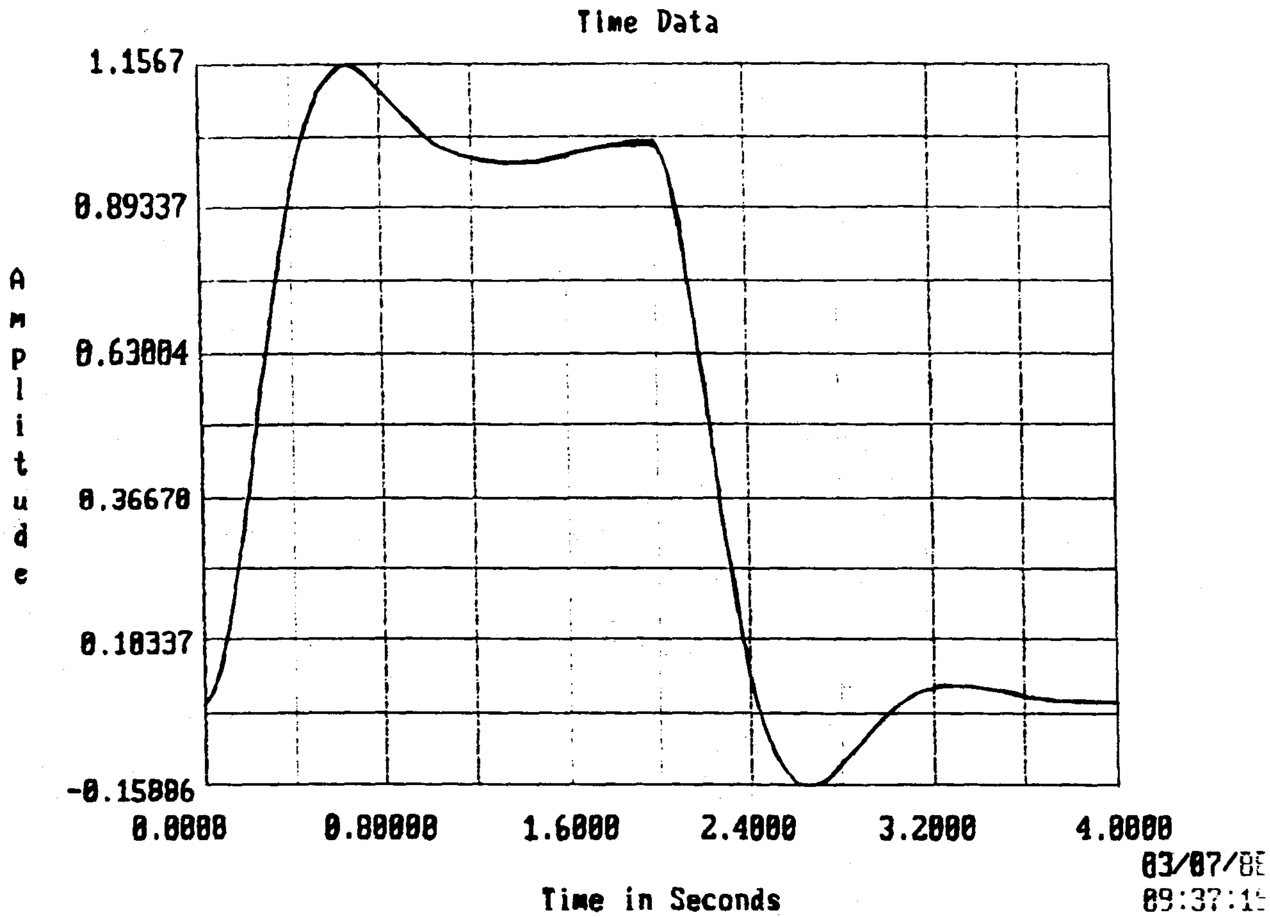


$K_a = 650 = (4.93)(39.5)(51.4)/(15.4)$

$K_f = 3\left(\frac{1}{.495}\right)\left(\frac{1}{4.97}\right)(2.7)/(51.4)$




HOOVER A6, OFF-LINE
6.0000
0.0000
-6.0000
-12.000
-18.000
-24.000
MAG DB
180.00
108.00
36.000
-36.000
-108.00
-180.00
0.01000
0.10000
1.0000
10.000
FREQUENCY


Time Data
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0.36670
0.10337
-0.15886
Amplitude
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0.80000
1.6000
2.4000
3.2000
4.0000
Time in Seconds
03/07/8
09:37:1

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.