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AUTOMATIC GENERATION CONTROL RESPONSE TESTS PERFORMED FOR WESTERN AREA POWER ADMINISTRATION'S UPPER COLORADO/LOWER MISSOURI CONTROL AREA

June 1994

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16. ABSTRACT

A summary of the work performed by Reclamation's Electric Power Branch to test the automatic generation control response of powerplants within the Western Area Upper Colorado/Lower Missouri combined control area is given.

17. KEY WORDS AND DOCUMENT ANALYSIS

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by

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Research and Laboratory Services Division
Denver Office
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U.S. Department of the Interior
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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; 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 ensure that their development is in the best interests of all our people by encouraging stewardship and 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.

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INTRODUCTION

In October 1993, Reclamation's Electric Power Branch in the Research and Laboratory Services Division received a request from Western (Western Area Power Administration) to test the AGC (automatic generation control) response within the WACM (Western Area Upper Colorado/Lower Missouri) combined control area. Attempts at control of the combined area revealed differences in generation response rates between Glen Canyon and Yellowtail powerplants. Performance related concerns existed regarding the data transfer delays between the associated control centers at Montrose, Colorado; Loveland, Colorado; Page, Arizona; and Casper, Wyoming. Therefore, Western requested that the Electric Power Branch review the generation response capability of the powerplants in the combined control area.

A proposal for the work was drafted and presented at a meeting between Reclamation and Western personnel on September 7, 1993. After some revision, this proposal was accepted. During the September meeting, a schedule for testing at each of the four control centers was prepared. After the meeting, a test procedure was written and sent to each of the control centers for review. The testing was initiated in October and completed during the week of November 29, 1993.

This report documents the results from the testing and presents conclusions based on the test results. Observations made while executing tests at the control centers are also included. A simple model of the system was constructed. Conclusions are made based on laboratory model tests. Recommendations are made to improve AGC control of the combined control area. A short-term modification is suggested to make the AGC more functional; however, a long-term direction must be pursued to provide AGC regulation from multiple powerplants in WACM while maintaining Reclamation release schedules and constraints.

CONCLUSIONS

The following conclusions, which relate to the control response of Reclamation powerplants within the combined WACM control area, have been made after reviewing the test results:

Conclusion 1

Variations in the response of Reclamation powerplants do not significantly contribute to WACM regulation problems. Some variation occurs in generation response among the Reclamation powerplants. The mechanical governors at Glen Canyon have a slower on-line response than the electromechanical governors at Yellowtail. However, the unit and plant controllers at Glen Canyon are able to overcome this slow response to provide a plant response that is comparable to the Yellowtail response.

During tests to determine powerplant response to a fixed level of ACE (area control error), Glen Canyon was found to respond at a rate of 4.0 percent/minute (0.32 megawatts per second with 3 units or 486 megawatts on AGC). Yellowtail responded at a rate of 4.6 percent per minute (0.19 megawatts per second with 4 units or 248 megawatts on AGC). These response rates were measured from the time the ACE pulse began to the time it was reset. Glen Canyon will normally respond faster in megawatts per minute because it normally has a larger capacity on AGC than Yellowtail.

Some of the plants could be "tuned" to improve their performance. However, at best these improvements will result in no more than a 10-percent increase in response rate. This level of improvement in plant generation response will have little effect on the combined area AGC.

The area AGC must be able to contend with nonlinear generation response. No amount of tuning can overcome the nonlinear response of plants and units. Nonlinear response implies that the units respond at a different rate in the raise direction than in the lower direction. Speed level motors, mechanical governors, and turbine efficiency characteristics all contribute to the nonlinear response of the units. Nonlinear and varying response of plant units contribute to a nonlinear plant generation response.

Reclamation has been working to improve this response by developing digital governors and improving unit controllers. Digital governors will minimize the nonlinear effects of speed level motors and the turbine by using adaptive control techniques. Improved unit controllers will minimize nonlinear characteristics of mechanical governors. However, the AGC must not depend on linear powerplant generation control characteristics.

Conclusion 2

Data transfer delays between the control center computers are not significant and do not contribute to WACM regulation problems. Control or data transfer delays average 3 seconds between the control centers. In other words, a control change takes about 3 seconds to get from Montrose to Page. Additionally, this change takes another 2 to 4 seconds to affect the governor speed level motor. The data transfer delay from Montrose to Loveland averages about 3 seconds, and the delay from Loveland to Casper also averages about 3 seconds. Delay for execution of control at the unit governor is again about 2 to 4 seconds for Casper. Therefore, the total delay from Montrose to affect governor speed level motors at Yellowtail averages 9 seconds. The same delay from Montrose to Glen Canyon averages 6 seconds. Delays of up to 10 seconds do not adversely affect the control response because the total control response time to a megawatt step change for the powerplants is normally 1.5 to 2 minutes.

The delay in tieline monitoring was measured during manual generation decreases at Glen Canyon and Yellowtail. Delays for the WALM (Western Area Lower Missouri) tieline measurements to reach the Montrose data base last about 4 to 8 seconds. The delays for the WAUC (Western Area Upper Colorado) tieline measurements to reach the Montrose data base last about 2 to 4 seconds. Again, these data transfer delays do not adversely affect the control response.

Conclusion 3

Use of the present ACE signal does not provide an accurate method of allocating desired regulation among multiple powerplants. The Montrose control center has the ability to send a portion of the ACE to Loveland and the remaining portion to Page. Normally, this factor is set so half the ACE is sent to Loveland and half is sent to Page. Tests showed that powerplant response rate is related somewhat to the level of ACE. However, the ACE is an error signal that dictates a particular resource should raise or lower. The ACE does not indicate how much the resource should raise or lower. Therefore, regulation requirements are difficult to distribute among a group of resources with any accuracy. Changes in plant response affect the allocation of regulation between multiple plants using this method of control because of the following: number of units on AGC, variations in plant response rates in the up and down directions, and variations of response among different units in a plant.

A setpoint scheme provides more accuracy and the ability to allocate generation among resources. The setpoint scheme implies that closed loop control of generation is performed at the level necessary to deal with response dynamics. For example, a generator is controlled to a generation setpoint by a unit controller. This controller operates the unit governor to maintain the generation setpoint in such a way as to overcome the governor's nonlinear response. The powerplant controller allocates generation setpoints to the various units to maintain unit rate limits, avoid rough zones, and improve total efficiency. However, the powerplant controller does affect or control unit dynamics because the generation setpoint is passed to the unit controller. The unit controller is responsible for unit response characteristics. Control at the power system level should work much the same way. Powerplant setpoints from the AGC should dictate the resource requirements from those plants while the corresponding powerplant controllers should then control the powerplant response characteristics. The setpoint scheme would dictate the exact generation level at which a particular resource should operate. This resource may be a single powerplant or a group of powerplants. Resources which encounter limits would not be used and AGC regulation would be shifted to other nonlimited resources.

The setpoint control scheme would also give the powerplant controller the responsibility for correcting the generation drift observed in the powerplant control response. When zero ACE is sent to a plant (no control), the powerplant governors continue to complete their response toward their last dictated speed level setting. This generation movement occurs until the governor response is complete or ACE drives the plant in the opposite direction. This reaction implies that the AGC must be adjusted to provide stable powerplant response characteristics. If the setpoint control method was implemented, the powerplant controllers would each take responsibility for their response characteristics.

Conclusion 4

Additional regulation from Reclamation powerplants could be obtained if avoidance of rough zones was automatically coordinated between Reclamation Control Centers and Western Dispatch Centers. During the Montrose tests, an operator at Casper eventually became alarmed that the Yellowtail generators were being driven back and forth across their rough zones. He executed a standard procedure to prevent rough zone operation by taking one of the units off control. This procedure tends to avoid constant movement across the rough zone, but decreases the regulation available from Yellowtail.

The Casper plant control software automatically allocates plant generation requirements to the Yellowtail units to avoid running them in the rough zone, but when AGC regulation places units near these zones, the units are forced to move back and forth across them. If the AGC could avoid running the Yellowtail plant at this level, and allocate the generation in the down direction to other powerplants when Yellowtail is close to the rough zones, then the operator at Casper would not have to reduce regulation by taking units off control. In fact, more units would probably be made available for AGC if this type of control was implemented. Therefore, additional regulation would be available and less control activity would be forced on a single powerplant.

The control centers have implemented rough zone avoidance and rate limit control for allocation of ACE among their own resources. However, coordination is required when allocating generation to powerplants across the total WACM control area. Future references to rough zone avoidance and rate limit control refer to the need for this coordination when allocating generation requirements to powerplants within the total WACM control area.

OBSERVATIONS

As a result of the testing, the following observations are offered in connection with improving the control of the combined control area:

1. There is a desire to use the WALM generation to meet WALM loads over an extended time frame. This desire has been interpreted by the dispatcher to mean that the WALM tieline schedule should be maintained all of the time. At present, no method of achieving this goal while providing AGC regulation has been automatically provided. Therefore, the dispatcher at Loveland manually controls the ACE received from Montrose and the "Delta," which is the difference between scheduled ties and actual ties.

Maintaining the ACE and the "Delta" over the same short time frame is impossible. The reason for maintaining ACE is to service changing internal area loads that cannot be predicted. Control criteria, which force ACE to cross zero every 10 minutes, have been determined by NERC (North American Electric Reliability Council). If the "Delta" is maintained and required to stay close to zero in the same time frame as ACE (once every 10 minutes), then no deviation from the schedule is allowed. If these criteria are followed, then no regulation or ACE control can be performed. Therefore, the time frame for maintaining "Delta" must be determined. For example, it may only be necessary for the integral of "Delta" to cross zero or return to the schedule once every month. This criterion would allow ACE regulation over the short time frame while maintaining the "Delta" only over a longer time frame.

Coordination of these two objectives must be provided. At the present time, the dispatcher provides this coordination manually. No amount of tuning of the present system will allow combined AGC regulation to take place while maintaining the WALM Schedule. A mathematical model was constructed to observe this behavior in the laboratory. The results of this model test are shown in appendix B. The WALM "Delta" will naturally drift when regulation for the combined control area occurs with WALM powerplants because plants respond differently in the up and down directions.

If the objective to use WALM generation to maintain WALM loads is strictly maintained without allowing any AGC regulation, then WALM is essentially operating as a separate control area that does not provide any combined AGC regulation. This operation implies that the consolidation makes AGC regulation of the WACM control area fall to the WAUC portion of the system and makes any benefits from the consolidation harder to achieve.

Another consideration when the two areas are combined is the load flow between the areas. The load flow studies showed that little generation from Glen Canyon can service WALM loads, and likewise, little generation from Yellowtail can service WAUC loads. During a test, Yellowtail was manually unloaded by 100 megawatts and Glen Canyon was used to replace this generation loss. Of the 100-megawatt generation increase supplied by Glen Canyon, only 15 megawatts were found to flow from WAUC to WALM. Therefore, when a generation increase in the WAUC portion of the WACM control area is used to service a load increase in the WALM portion, the power does not normally flow over WACM transmission lines. Power requirements between WAUC and WALM normally flow on transmission paths external to the WACM system.

2. Rate limits on Reclamation generation are normally maintained manually. Rate limits and actual rates are not telemetered from Reclamation to Western. When ACE is used for control, the AGC assumes that Reclamation maintains the plants at a rate limit. The dispatchers manually observe the limits, but no automatic rate limit is imposed. If multiple plants can be used for regulation, then ideally, the AGC should not drive individual powerplants beyond rate limits.

New SCADA (supervisory control and data acquisition) systems are being procured for both Montrose and Loveland. These new systems will provide improved methods to allocate regulation to multiple powerplants while maintaining rate limits.

SHORT-TERM RECOMMENDATIONS

A simple change could be implemented to maintain the WALM Delta (the difference between the WALM actual ties and the WALM schedule for the ties) over a longer term while providing some regulation. This change should be made at Montrose and would distribute ACE between Montrose and Page to provide regulation in the short term and slowly move the WALM Delta toward zero over a longer term. Several algorithms could be used to accomplish the objective. Proposed algorithms should be modeled in the laboratory to determine viability before implementation proceeds.

In addition, the ACE portion sent to Page should be set to maximize regulation from both Glen Canyon and Yellowtail. Neither plant should bear more regulation burden than the other. The standard setting of 0.5 (half the ACE sent to Page) normally requires more regulation burden from Yellowtail and less from Glen Canyon when the capacity of the plants is taken into account. A setting of 0.7 (70 percent of the ACE sent to Page) would generally distribute the burden equally.

LONG-TERM RECOMMENDATIONS

The long-term recommendations will require additional effort; however, both Reclamation and Western will benefit from these improvements. Therefore, some method of performing the work with involvement from both agencies must be pursued.

1. Use setpoints to control the various powerplants (or group of powerplants) rather than the ACE signal. This modification is already planned for the Montrose to Page datalink. Notice that setpoints may be used for a single plant or a group of plants. Therefore, plants in the WALM Area may be controlled from Loveland as a group if desired.

2. Reclamation should continue to pursue improvements in powerplant response by performing alignments and setting criteria for alignment of unit control software. The application of digital governors should also be pursued to minimize nonlinear response from Reclamation powerplants.

3. Improved coordination between the AGC and powerplant controllers should be pursued. Reclamation powerplant controllers need to provide data on limits and water usage to Western's AGC. The AGC must then use those data to maintain releases and improve efficiency while performing regulation. Figure one proposes a generalized interface between the AGC and powerplant controllers. This proposal would provide data about rough zones, incremental cost, rate limits, and energy (or water usage) on the link to the AGC. The powerplant controllers would calculate these data, and the AGC would use these data to improve operations by minimizing cost (water usage), avoiding rough zones, maintaining rate limits, and maintaining energy schedules.

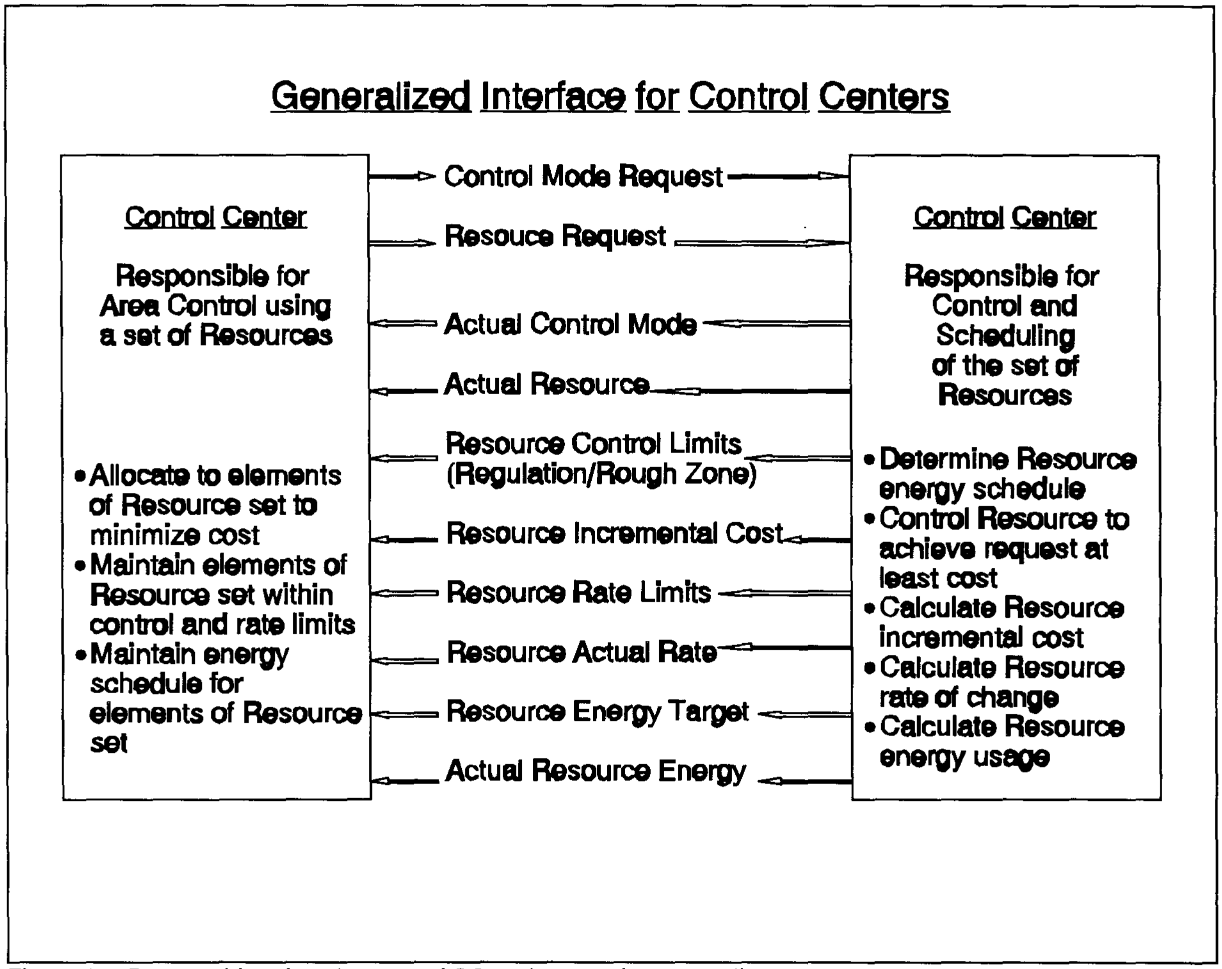


Figure 1. - Proposed interface between AGC and powerplant controllers.

WORK SUMMARY

As shown in the test procedure, one of the objectives of the tests was to take data on a 1-second cycle at each control center. The 1-second data had to be time stamped using radio station WWVB time data, available at each control center, so data transfer delays between the control centers could be measured. The Western control centers at Montrose and Loveland had previously developed a data recording method. However, each of the Reclamation control centers at Casper, Wyoming, and Page, Arizona, had to develop a data recording package. Western staff at Montrose performed load flow studies to determine the normal load flow patterns in the WACM system.

The primary purpose for the testing was to determine the response of the Reclamation generators and powerplants. Speed level motor run times and on-line governor time constants were measured for each available unit. Data from these tests are given under the heading **Governor Response** in appendix A. The generation step response of each unit is given under the heading **Unit Control Response**. Powerplant step response data are given under the heading **Plant Control Response**. An individual generation setpoint received from Loveland controls Seminoe and Kortes powerplants. Alcova and Fremont Canyon also have an individual generation setpoint. Step response tests were performed for both of these setpoint controllers at the Casper Control Center. Step response tests for Yellowtail were performed from Casper and Loveland. Step response tests for Glen Canyon were performed at Page.

Response of the AGC was tested by performing two types of tests. First, an ACE pulse was used to determine the powerplant controlled response. An ACE pulse was sent to Loveland to observe the Yellowtail response, and an ACE pulse was sent to Page to observe the Glen Canyon response. Second, response of the AGC was tested by introducing a step change in the WACM tieline schedules at Montrose. These AGC step tests were performed with Glen Canyon and Yellowtail powerplants on AGC.

The primary focus is the powerplant response data given in appendix A. In summary, the powerplant response from both Yellowtail and Glen Canyon is adequate. The Yellowtail and Glen Canyon step responses were completed within 2 minutes in all cases. The total response to a normal ACE (10 megawatts) pulse was about 4 to 6 percent/minute for both plants. Under assist conditions (30-megawatt ACE), Glen Canyon was found to respond at 7 to 8 percent/minute.

After the testing was completed, a simple model of the system was constructed using a laboratory simulation. The simulation was built to study the drift in the WALM internal scheduled tielines during normal AGC regulation. Descriptions of the model developed and the laboratory responses are given in appendix B.

APPENDIX A

AGC Response Test Results

AGC TEST DATA

12/10/93
S. Stitt

The following test data are divided into five major sections: **Governor Response, Unit Control Response, Plant Control Response, Plant Response to ACE**, and **Plant Response to a Tieline Schedule Change**. Simple explanations of the data taken with some analysis are given prior to each section.

Governor Response

These tests measured speed level motor run time and the governor time constants for each unit tested. The speed level run times up and down are given in seconds per percent. Normally, 5 percent is considered full travel for the speed level motor, and a 10-second-per-percent travel time is recommended. This time provides good resolution while maintaining response time at a reasonable level.

The Upper Colorado speed level motors run much faster than recommended. These fast motors make controller adjustment more difficult. Project personnel will investigate and correct this problem when governor annual maintenance occurs.

The governor time constants were measured by manually stepping the speed level motor up and down from the control board. Therefore, these time constants cannot be considered a true measurement but are a good approximation. The governors at Glen Canyon are slower because they have no dashpot bypass. However, the generation controls function adequately with these slower governors.

Definitions

SLM Up(Dn) - Run time of the speed level motor in the raise (up) or lower (down) direction.

Time Const Up(Dn) - Time for generation to move 63 percent (one time constant) of travel in the up or down direction when a step change to the speed level is made manually from the control board.

Governor Response

Measured from Casper Control Center

	YEL1	YEL2	YEL3	YEL4
SLM Up	8.8 s/%	10.0 s/%	14.4 s/%	13.9 s/%
Time Const Up	27.5 s	17 s	21.5 s	28 s
SLM Dn	10.4 s/%	15.2 s/%	11.8 s/%	10.8 s/%
Time Const Dn	33 s	23 s	24 s	26 s

	FRE1	FRE2	ALC1	ALC2
SLM Up	n/a	No Acc	n/a	8.4 s/%
Time Const Up	n/a	23 s	n/a	19 s
SLM Dn	n/a	No Acc	n/a	7.4 s/%
Time Const Dn	n/a	25 s	n/a	14 s

	SEM1	SEM2	SEM3
SLM Up	8.1 s/%	n/a	n/a
Time Const Up	50 s	n/a	n/a
SLM Dn	6.7 s/%	n/a	n/a
Time Const Dn	35 s	n/a	n/a

	KOR1	KOR2	KOR3
SLM Up	n/a	n/a	13.7 s/%
Time Const Up	n/a	n/a	25 s
SLM Dn	n/a	n/a	11.9 s/%
Time Const Dn	n/a	n/a	61 s

Measured from Loveland Control Center

	Estes1	Estes2	Estes3
SLM Up	21.6 s/%	n/a	8.4 s/%
Time Const Up	28 s	n/a	25 s
SLM Dn	23.2 s/%	n/a	8.2 s/%
Time Const Dn	24 s	n/a	23 s

	Flatiron1	Flatiron2
SLM Up	15.7 s/%	n/a
Time Const Up	14 s	n/a
SLM Dn	14.6 s/%	n/a
Time Const Dn	8 s	n/a

	Mt.Elbert1	Mt.Elbert2
SLM Up	8.7 s/%	9.5 s/%
Time Const Up	28 s	28 s
SLM Dn	9.5 s/%	10.9 s/%
Time Const Dn	26 s	17 s

Measured from CRSP (Colorado River Storage Project) Control Center (Page)

	GC1	GC2	GC3	GC4
SLM Up	1.7 s/%	4.0 s/%	n/a	1.3 s/%
Time Const Up	20 s	50 s	n/a	12 s
SLM Dn	2.5 s/%	3.3 s/%	n/a	2.0 s/%
Time Const Dn	34 s	43 s	n/a	14 s

	GC5	GC6	GC7	GC8
SLM Up	n/a	3.3 s/%	2.5 s/%	2.0 s/%
Time Const Up	n/a	52 s	34 s	56 s
SLM Dn	n/a	2.9 s/%	1.7 s/%	2.2 s/%
Time Const Dn	n/a	72 s	53 s	44 s

	BLM1	BLM2	MP1	MP2
SLM Up	3.6 s/%	4.2 s/%	7.3 s/%	5.0 s/%
Time Const Up	20 s	20 s	38 s	48 s
SLM Dn	4.0 s/%	4.7 s/%	5.7 s/%	6.0 s/%
Time Const Dn	20 s	18 s	35 s	52 s

	FG1	FG2	FG3	CR1
SLM Up	5.7 s/%	5.0 s/%	2.0 s/%	n/a
Time Const Up	20 s	26 s	30 s	n/a
SLM Dn	6.7 s/%	2.9 s/%	5.7 s/%	n/a
Time Const Dn	18 s	20 s	42 s	n/a

Unit Control Response

These tests measured the response of the individual units while under setpoint control. A step change in the generation setpoint was made in the raise and lower directions. Response to the step change was measured. Two criteria were measured. The first was the time to reach 10 percent of the expected change, and the second was the time to travel from 10 percent to 90 percent of the expected change. The response data for some of the units indicate some adjustment is necessary. For example, the Morrow Point units and Flaming Gorge unit 3 have a slow response. Some coordination in operation of the governor dashpot bypasses may be necessary. The controllers at Glen Canyon have an unusually large amount of variation in their responses. In addition, the Mt. Elbert controllers had a large deadband. These problems are not critical, but should be reviewed when annual governor maintenance is performed.

Definitions

MW Step Up(Dn) - The step change in generation up (raise) or down (lower) sent to the unit controller.

10% MW change - The time required to reach 10 percent of the expected generation step change.

10%-90% Up(Dn) - The time required for the unit to move from 10 percent to 90 percent of the expected response.

Unit Control Response Data

Measured from Casper Control Center

	YEL1	YEL2	YEL3	YEL4
MW Step Up	35-55 MW	35-55 MW	17-55 MW	35-55 MW
10% MW change	19 s	15 s	15 s	19 s
10%-90% Up	45 s	50 s	68 s	54 s
MW Step Dn	55-35 MW	55-20 MW	55-35 MW	55-35 MW
10% MW change	11 s	13 s	20 s	10 s
10%-90% Dn	45 s	57 s	84 s	52 s

	FRE1	FRE2	ALC1	ALC2
MW Step Up	n/a	10-20 MW	n/a	5-15 MW
10% MW change	n/a	15 s	n/a	8 s
10%-90% Up	n/a	87 s	n/a	88 s
MW Step Dn	n/a	20-10 MW	n/a	15-5 MW
10% MW change	n/a	11 s	n/a	12 s
10%-90% Dn	n/a	86 s	n/a	99 s

	SEM1	SEM2	SEM3
MW Step Up	5-12 MW	n/a	n/a
10% MW change	41 s	n/a	n/a
10%-90% Up	108 s	n/a	n/a
MW Step Dn	12-5 MW	n/a	n/a
10% MW change	31 s	n/a	n/a
10%-90% Dn	89 s	n/a	n/a

	KOR1	KOR2	KOR3
MW Step Up	n/a	n/a	5.25-12.0 MW
10% MW change	n/a	n/a	30 s
10%-90% Up	n/a	n/a	82 s
MW Step Dn	n/a	n/a	12.0-7.1 MW
10% MW change	n/a	n/a	20 s
10%-90% Dn	n/a	n/a	56 s

Measured from the Loveland Control Center

	Estes1	Estes2	Estes3
MW Step Up	6 - 12 MW	n/a	6 - 12 MW
10% MW change	20 s	n/a	23 s
10%-90% Up	72 s	n/a	151 s
MW Step Dn	12 - 6 MW	n/a	12 - 6 MW
10% MW change	18 s	n/a	14 s
10%-90% Dn	88 s	n/a	161 s

	Flatiron1	Flatiron2
MW Step Up	25 - 40 MW	n/a
10% MW change	39 s	n/a
10%-90% Up	85 s	n/a
MW Step Dn	40 - 25 MW	n/a
10% MW change	41 s	n/a
10%-90% Dn	114 s	n/a

	Mt.Elbert1	Mt.Elbert2
MW Step Up	65 - 95 MW	65 - 85 MW
10% MW change*	41 s	35 s
10%-90% Up*	73 s	119 s
MW Step Dn	95 - 65 MW	85 - 65 MW
10% MW change*	33 s	42 s
10%-90% Dn*	100 s	124 s

* - 20%-80% and 4-MW deadband for unit 1 only

Measured from CRSP Control Center (Page)

	GC1	GC2	GC3	GC4
MW Step Up	110-150 MW	110-150 MW	n/a	110-150 MW
10% MW change	28 s	36 s	n/a	16 s
10%-90% Up	120 s	138 s	n/a	96 s
MW Step Dn	150-110 MW	150-110 MW	n/a	150-110 MW
10% MW change	36 s	46 s	n/a	34 s
10%-90% Dn	98 s	118 s	n/a	89 s

	GC5	GC6	GC7	GC8
MW Step Up	n/a	110-150 MW	110-150 MW	110-150 MW
10% MW change	n/a	28 s	24 s	38 s
10%-90% Up	n/a	126 s	114 s	144 s
MW Step Dn	n/a	150-110 MW	150-110 MW	150-110 MW
10% MW change	n/a	34 s	34 s	102 s
10%-90% Dn	n/a	90 s	100 s	141 s

	BLM1	BLM2	MP1	MP2
MW Step Up	15-35 MW	15-35 MW	35-65 MW	35-65 MW
10% MW change	38 s	14 s	34 s	42 s
10%-90% Up	198 s	131 s	198 s	254 s
MW Step Dn	35-15 MW	35-15 MW	65-35 MW	65-35 MW
10% MW change	42 s	22 s	46 s	42 s
10%-90% Dn	176 s	118 s	189 s	250 s

	FG1	FG2	FG3	CR1
MW Step Up	25-40 MW	25-40 MW	25-40 MW	n/a
10% MW change	28 s	18 s	72 s	n/a
10%-90% Up	132 s	126 s	354 s	n/a
MW Step Dn	40-25 MW	40-25 MW	40-25 MW	n/a
10% MW change	38 s	42 s	60 s	n/a
10%-90% Dn	140 s	136 s	258 s	n/a

Plant Control Response

The data taken for the Plant Control Response tests were similar to the data taken for the Unit Control Response tests. No response problems were detected with the powerplants tested.

Definitions

AGC Units - A list of units which were on AGC when the step test was performed is given.

Plant Control Response Data

Measured from Casper Control Center

	YELLOWTAIL	SEMINOE/KORTES	ALCOVA/FREMONT
AGC Units	1,2,3,4	SEM1,KOR3	ALC1,FRE2
MW Step Up	60-100 MW	14-22 MW	24-35 MW
10% MW change	23 s	35 s	19 s
10%-90% Up	52 s	93 s	85 s
MW Step Dn	100-60 MW	22-14 MW	35-25 MW
10% MW change	18 s	43 s	35 s
10%-90% Dn	68 s	93 s	101 s

Measured from Loveland Area Office

	YELLOWTAIL
AGC Units	1,2,3,4
MW Step Up	100-140 MW
10% MW change	28 s
10%-90% Up	52 s
MW Step Dn	140-100 MW
10% MW change	28 s
10%-90% Dn	51 s

Measured from CRSP Control Center (Page)

	GC345
AGC Units	1,2,4,6
MW Step Up	400-450 MW
10% MW change	16 s
10%-90% Up	36 s
MW Step Dn	450-400 MW
10% MW change	18 s
10%-90% Dn	42 s

Plant Response to ACE

During this series of tests, an ACE pulse was delivered to each of the powerplants tested to move generation up and down. No problems with plant response were detected. The powerplant response was increased when the pulse amplitude was increased beyond the megawatt assist level. The pulse allowed for convenient measurement of the data transfer delay between the control centers.

Definitions

ACE Pulse down(up) - The level or amplitude of the ACE pulse

Pulse duration - The amount of time the pulse was applied

MW change - The total plant generation change from pulse start to pulse end

Rate - Calculation of the rate the plant moved in megawatts per second

Page Delay - The data transfer delay in seconds between the time the pulse was sent from the Montrose control center data base until it reached the Page control center data base

MW Drift - The amount the powerplant continued to drift after the pulse was reset

Plant Response to ACE

	GC345 Frm CRSP	Yellowtail Frm Loveland
AGC Units	2,4,6	1,2,3,4
ACE Pulse down	-10 MW	-10 MW
Pulse duration	76 s	160 s
MW change	382-406 MW	178-208 MW
Rate	0.32 MW/s (4.0%/min)	0.19 MW/s (4.6%/min)
ACE Pulse up	10 MW	10 MW
Pulse duration	72 s	168 s
MW change	405-381 MW	216-185 MW
Rate	0.33 MW/s (4.1%/min)	0.18 MW/s (4.4%/min)

	GC345 Frm Montrose	GC345 Frm Montrose	GC345 Frm Montrose
AGC Units	1,2,4,6	1,2,4,6	1,2,4
ACE Pulse down	-10 MW	-30 MW	-10 MW
Page Delay	4 s	3 s	2 s
Duration	133 s	92 s	103 s
MW change	336-398 MW	311-395 MW	328-378 MW
MW Drift	417 MW	411 MW	383 MW
Rate	0.47 MW/s (4.3%/min)	0.91 MW/s (8.4%/min)	0.49 MW/s (6.0%/min)
ACE Pulse up	10 MW	30 MW	10 MW
Page Delay	3 s	4 s	5 s
Duration	156 s	54 s	98 s
MW change	447-368 MW	409-367 MW	383-341 MW
MW Drift	333 MW	329 MW	323 MW
Rate	0.51 MW/s (4.7%/min)	0.78 MW/s (7.2%/min)	0.43 MW/s (5.3%/min)

	GC345 Frm Montrose	Yellowtail Frm Montrose
AGC Units	1,2	1,2,3,4
ACE Pulse down	-10 MW	-10 MW
Page Delay	3 s	n/a*
Duration	188 s	237 s
MW change	321-391 MW	134-184 MW
MW Drift	403 MW	193 MW
Rate	0.37 MW/s (6.8%/min)	0.21 MW/s (5.1%/min)
ACE Pulse up	10 MW	10 MW
Page Delay	4 s	n/a*
Duration	141 s	320 s
MW change	403-362 MW	193-115 MW
MW Drift	341 MW	96 MW
Rate	0.29 MW/s (5.4%/min)	0.24 MW/s (5.8%/min)

* The data taken at Casper did not allow data transfer delay to be measured during this test. Casper data transfer delay was measured during the tieline schedule change tests. This delay is about 6 seconds from the Montrose data base to the Casper data base.

Plant Response to a Tieline Schedule Change

During this series of tests, a change was made to the tieline schedule for the WACM control area. The control area response to a step change in the schedule was measured. The criterion used was the time for the ACE to cross zero. This test was performed with only the Glen Canyon (345-kilovolt bus) on AGC, with only Yellowtail on AGC, and with both plants on AGC. With both powerplants on control, various configurations of units on control and ACE multiplier value were also tested.

Definitions

ACE to Page - The multiplier used to determine what percent of the ACE is sent to the Page control center. With a setting of 0.5, half the ACE is sent to Page and half is sent to Loveland.

MW Tie Offset - The value of the step change, which was normally entered by changing the offset to a false value and then returning it to 0.

ACE Zero Crossing - The time in seconds for the ACE to cross zero.

Glen Response - The change in generation that occurred at Glen Canyon.

Yell Response - The change in generation that occurred at Yellowtail.

Plant Response to Tieline Schedule Change

	Frm Montrose	Frm Montrose
AGC Units	GC345 1,2,4,6	GC345 1,2
ACE to Page	1.0	1.0
MW Tie Offset	0 to -100 MW	0 to -50 MW
ACE Zero Crossing	128 s	104 s
MW Tie Offset	-100 MW to 0	-50 MW to 0
ACE Zero Crossing	120 s	84 s

	Frm Montrose	Frm Montrose
AGC Units	Yell 1,2,3,4	Yell 1,2,3,4
ACE to Page	0.0	0.0
MW Tie Offset	0 to -70 MW	0 to -50 MW
ACE Zero Crossing	98 s*	104 s (Casper Delay=6 s)
MW Tie Offset	0 to -50 MW	-50 to 20 MW
ACE Zero Crossing	103 s**	114 s

*Oscillatory with 35-MW ACE overshoot

**Oscillatory with -51-MW ACE overshoot

Note: The Loveland settings for Regulation Gain (from 1.1 to 1.0) and Assist Gain (from 1.25 to 1.0) were moved before the second series of tests was performed. This movement corrected the oscillation.

	Frm Montrose	Frm Montrose
AGC Units	GC345 1,2,4,6 Yell 1,2,3,4	GC345 1,2,4,6 Yell 1,2,3,4
ACE to Page	0.5	0.2
MW Tie Offset	-10 to 50 MW	0 to -50 MW
ACE Zero Crossing	86 s	103 s
Glen Response	502-461 MW (66%)	495-515 MW (33%)
Yell Response	176-155 MW (34%)	161-202 MW (67%)
MW Tie Offset	50 MW to 0	-50 MW to 0
ACE Zero Crossing	90 s	98 s
Glen Response	463-490 MW (63%)	515-484 MW (41%)
Yell Response	151-167 MW (37%)	205-160 MW (59%)

	Frm Montrose
AGC Units	GC345 1,2 Yell 1,2,3,4
ACE to Page	0.5
MW Tie Offset	0 to -50 MW
ACE Zero Crossing	109 s
Glen Response	468-497 MW (56%)
Yell Response	168-191 MW (44%)
MW Tie Offset	-50 MW to 0
ACE Zero Crossing	125 s
Glen Response	497-464 MW (55%)
Yell Response	190-163 MW (45%)

Unit Limits

		Capacity	Minimum	Rough Zone
Fremont Canyon	-	27 MW(2)	13 MW(1),2 MW(2)	n/a
Alcova	-	20 MW(2)	2 MW	n/a
Kortes 1	-	12.55 MW	1.5 MW	n/a
Kortes 2	-	12.30 MW	1.5 MW	n/a
Kortes 3	-	12 MW	1.5 MW	n/a
Seminoe 1	-	14 MW	2 MW	n/a
Seminoe 2&3	-	14.4 MW	1 MW	n/a
Yellowtail 1-4	-	62 MW	3 MW	17.5-31.5 MW
Estes 1-3	-	16.5 MW	0 MW	n/a
Flatiron 1-2	-	43 MW	5 MW	n/a
Mt. Elbert 1	-	106 MW	25 MW	n/a
Mt. Elbert 2	-	100 MW	25 MW	52-62 MW
Glen Canyon 1-8	-	162 MW	1 MW	n/a
Blue Mesa 1-2	-	42 MW	1 MW	n/a
Morrow Pt 1-2	-	78 MW	1 MW	n/a
Flaming Gor 1-3	-	47 MW	1 MW	n/a

PLOTTED DATA EXPLANATIONS

Eight plots of recorded data are included on the following pages. These plots were made to determine tieline monitoring delays and the WALM/WAUC power flow during the manual generation decrease tests at Yellowtail and Glen Canyon. The following explanations are given for each of the plots.

Load Flow during Yellowtail Generation Decrease

This plot shows the relationship of the WACM tielines to the WALM tielines during the Yellowtail manual generation decrease. About 100 megawatts are unloaded from Yellowtail powerplant. The tieline totals drop as Yellowtail is unloaded. Glen Canyon is used to overcome the loss in generation at Yellowtail. The WACM tielines increase as Glen Canyon generation increases.

WAUC Delay in WALM Tieline Monitoring

This plot is an expanded time base of the WACM tielines versus the Yellowtail Powerplant generation during the manual generation decrease. The Yellowtail generation is monitored using a Western RTU (remote terminal unit) at the plant. The delay between the Yellowtail generation and the WACM tielines in the Montrose data base provides a measure of the data transfer delay for WALM tieline monitoring at Montrose. This delay is between 4 and 8 seconds.

Glen Canyon Response to Yellowtail Generation Decrease

This plot shows the relationship between Glen Canyon and Yellowtail generation during the Yellowtail manual generation decrease. The tieline totals are shown for this test in the first plot described above. The delay for Glen Canyon to begin responding is about 30 seconds.

WAUC/WALM Load Flow during Yellowtail Generation Decrease

The figure shows that the power flow from WAUC to WALM increases as the WALM tielines decrease. However, the increase for the 100-megawatt power loss within WALM is only about 15 megawatts. So 15 percent of the generation loss is provided directly from WAUC. The rest must come from changing load flow external to the WACM control area.

Change in WACM Tielines during Glen Canyon 345-kilovolt Generation Decrease

This chart shows the relationship between Glen Canyon generation and the WACM total tielines. After Glen Canyon generation has decreased about 40 megawatts, Yellowtail begins to respond and the WACM tielines increase. However, Yellowtail encounters a limit and the WACM tielines continue to decrease with Glen Canyon generation. Apparently, another unmonitored generation source began to respond to the problems toward the end of the chart.

WAUC Delay in Tieline Monitoring

An expanded chart of the generation loss at Glen Canyon versus the WACM tielines is given. This chart allows measurement of the data transfer delay in monitoring the WAUC tielines in the Montrose data base. The delay lasts about 2 to 4 seconds.

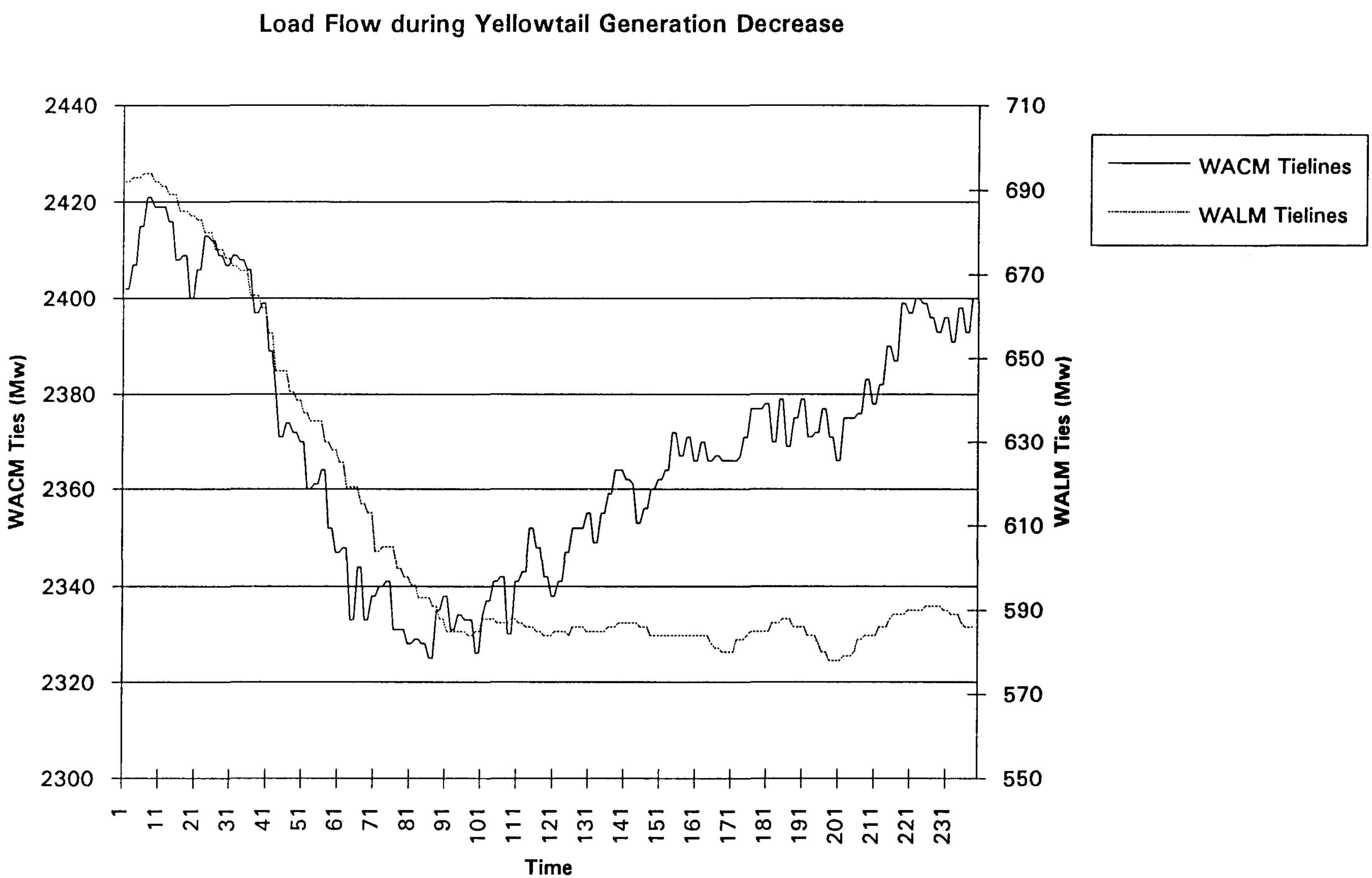
Yellowtail Generation Control during Glen Canyon Manual Generation Decrease

In this chart, Yellowtail responds with about 30 megawatts to the Glen Canyon decrease. The WAUC/WALM tielines unload by about 5 megawatts. Therefore, most of the generation loss at Glen Canyon must be overcome by transmission external to WACM.

Yellowtail Response to Glen Canyon Generation Decrease

This chart shows the Yellowtail response during the Glen Canyon decrease. Notice that Yellowtail is increasing slightly in generation at the time Glen Canyon starts to drop. The response from Yellowtail could not overcome the loss at Glen Canyon because the Casper operator had taken all but one Yellowtail unit off control.

CHART10.XLC



Load Flow during Yellowtail Generation Decrease
WACM Ties (Mw)
WALM Ties (Mw)
Time
WACM Tielines
WALM Tielines
2440
2420
2400
2380
2360
2340
2320
2300
710
690
670
650
630
610
590
570
550
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181
191
201
211
221
231

CHART6.XLC

WAUC Delay in WALM Tieline Monitoring

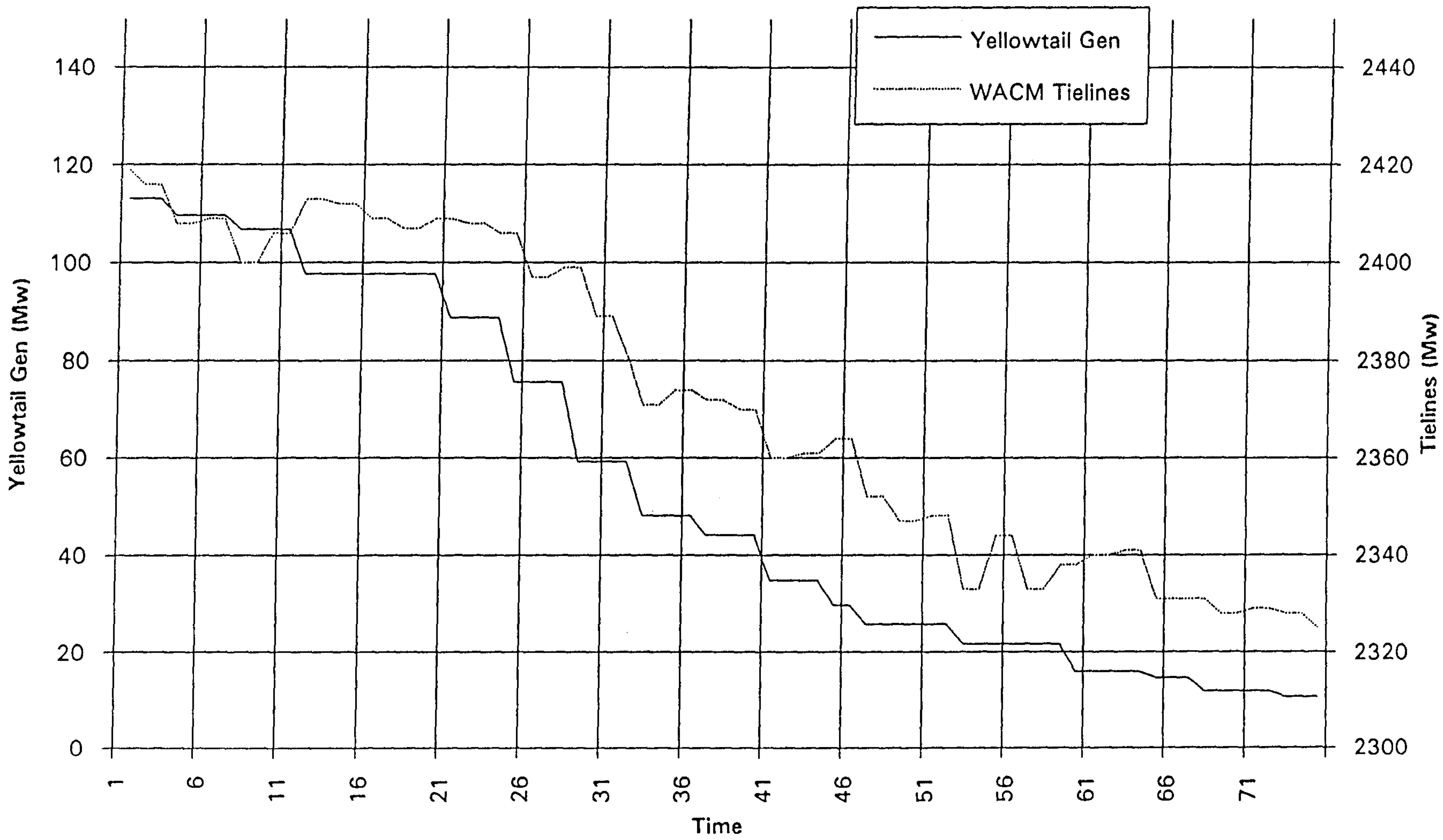
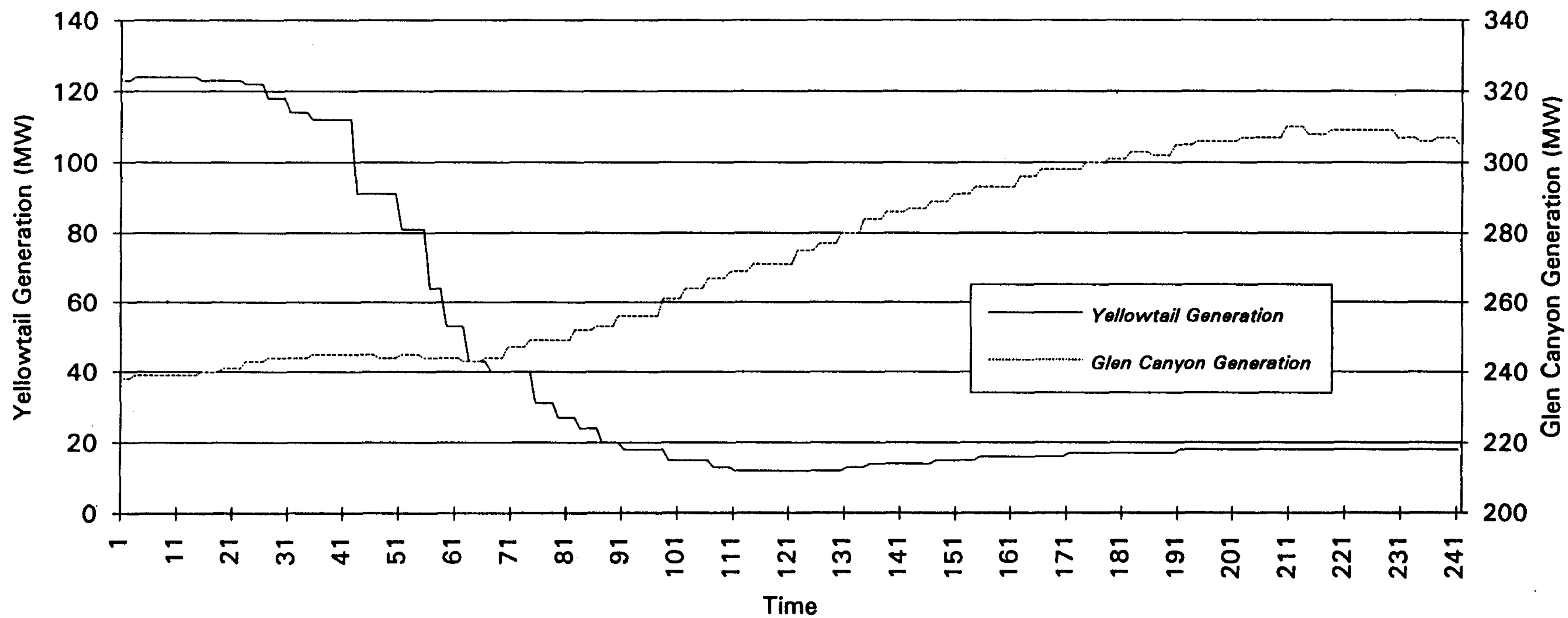


CHART99.XLC

GLEN CANYON RESPONSE TO YELLOWTAIL GENERATION DECREASE



DRPYE.70 Chart 11

WAUC/WALM Load Flow during Yellowtail Generation Decrease

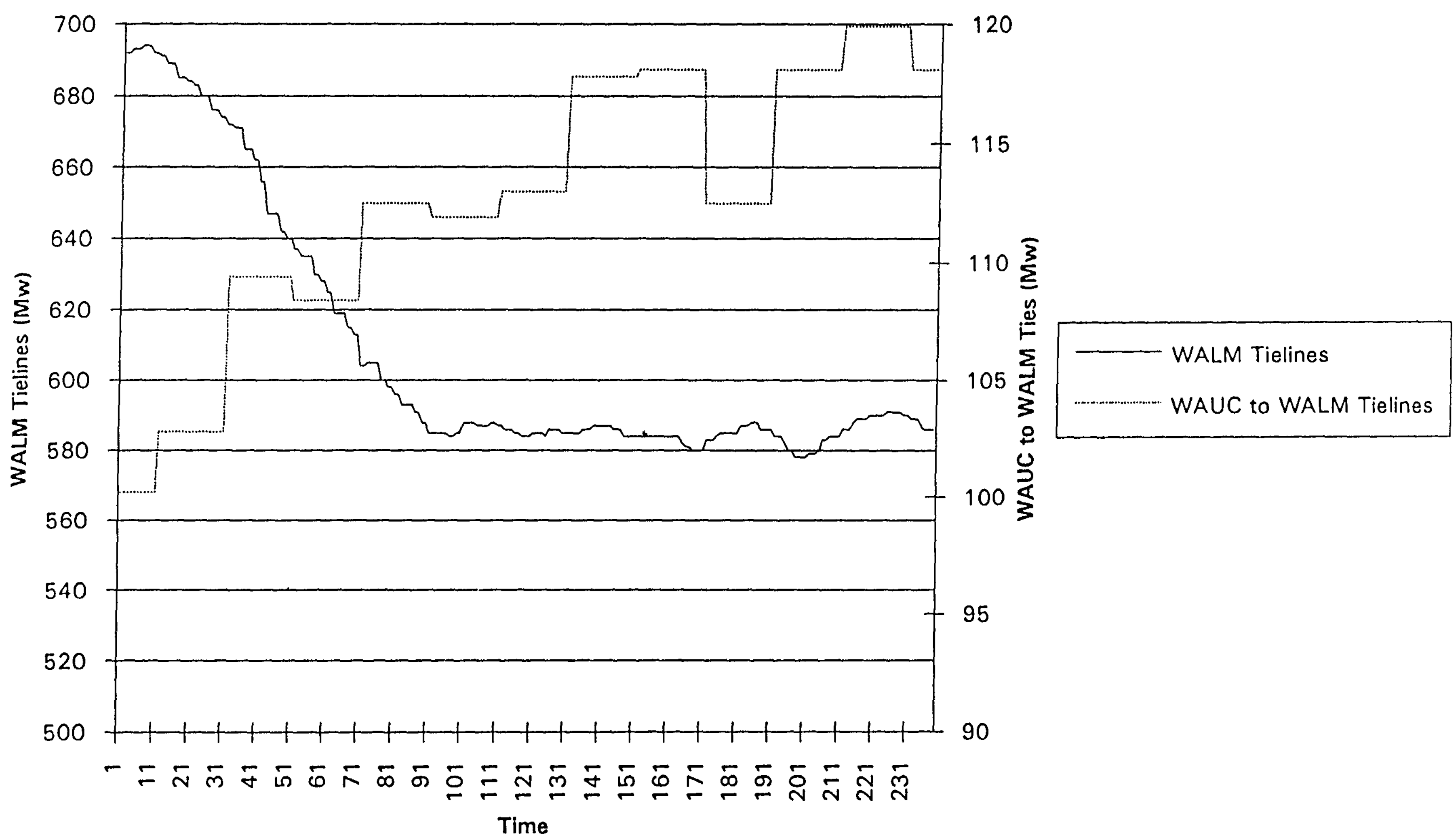
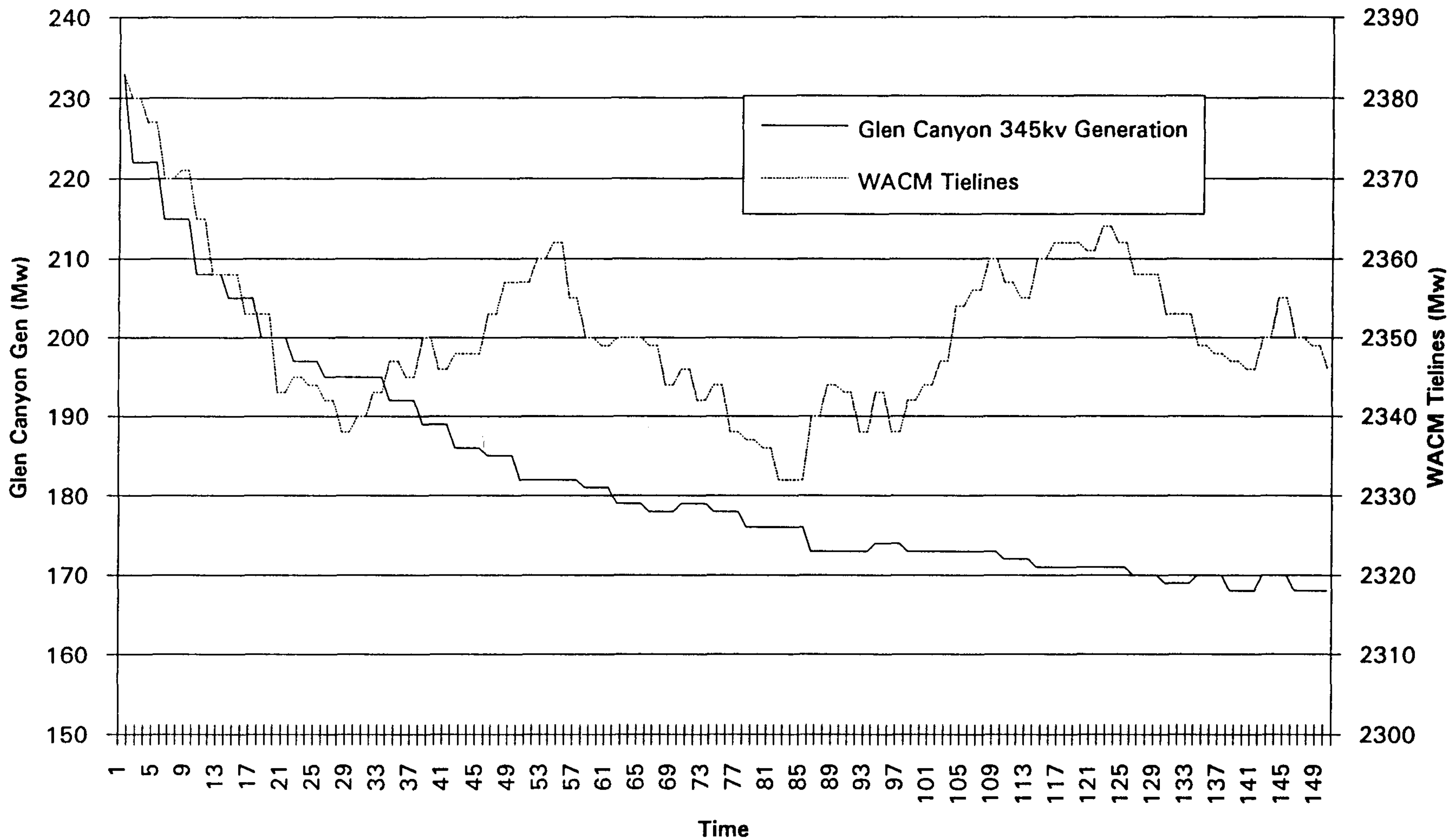
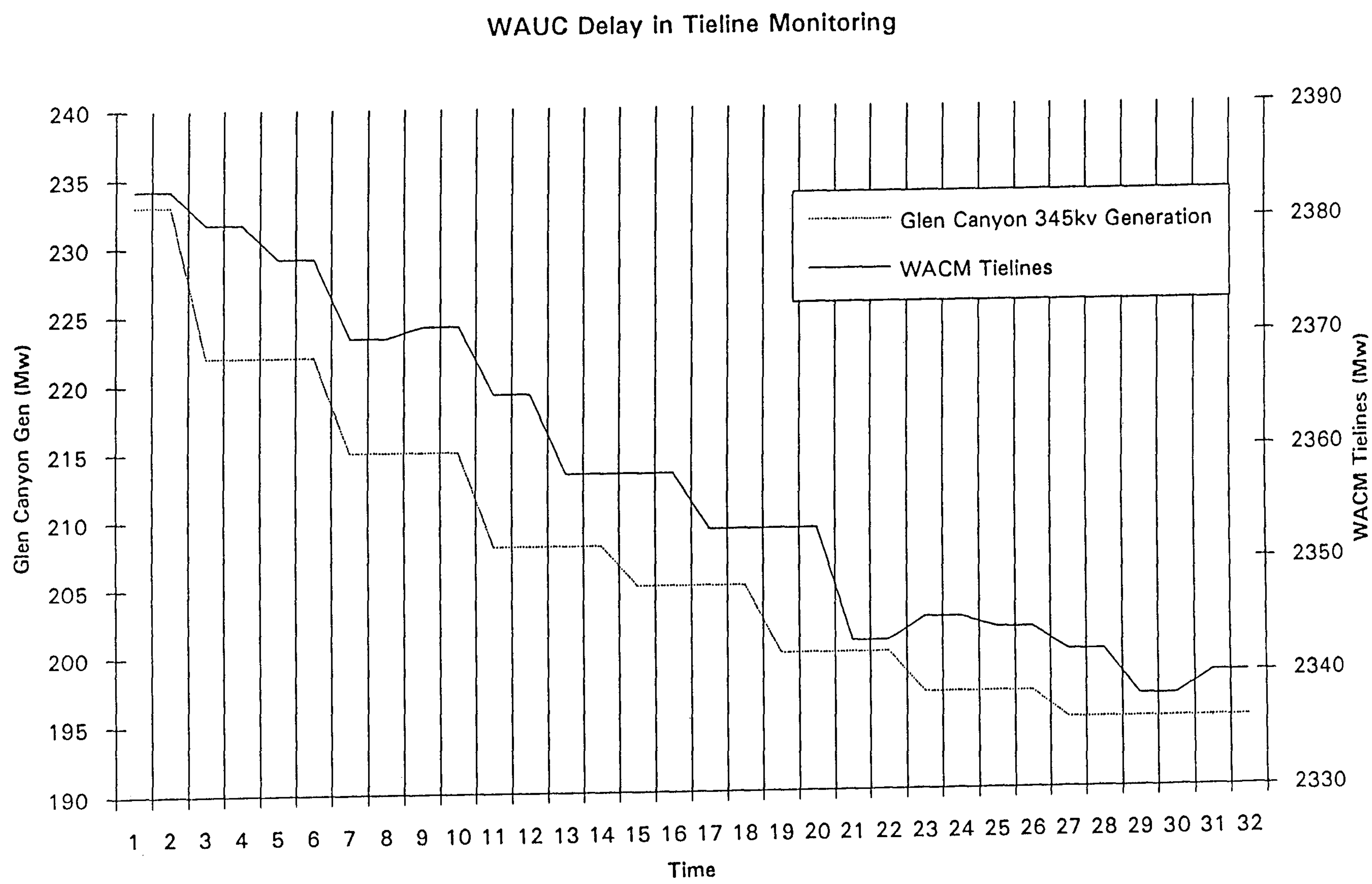


CHART8.XLC

Change in WACM Tielines during Glen Canyon 345kv Generation Decrease

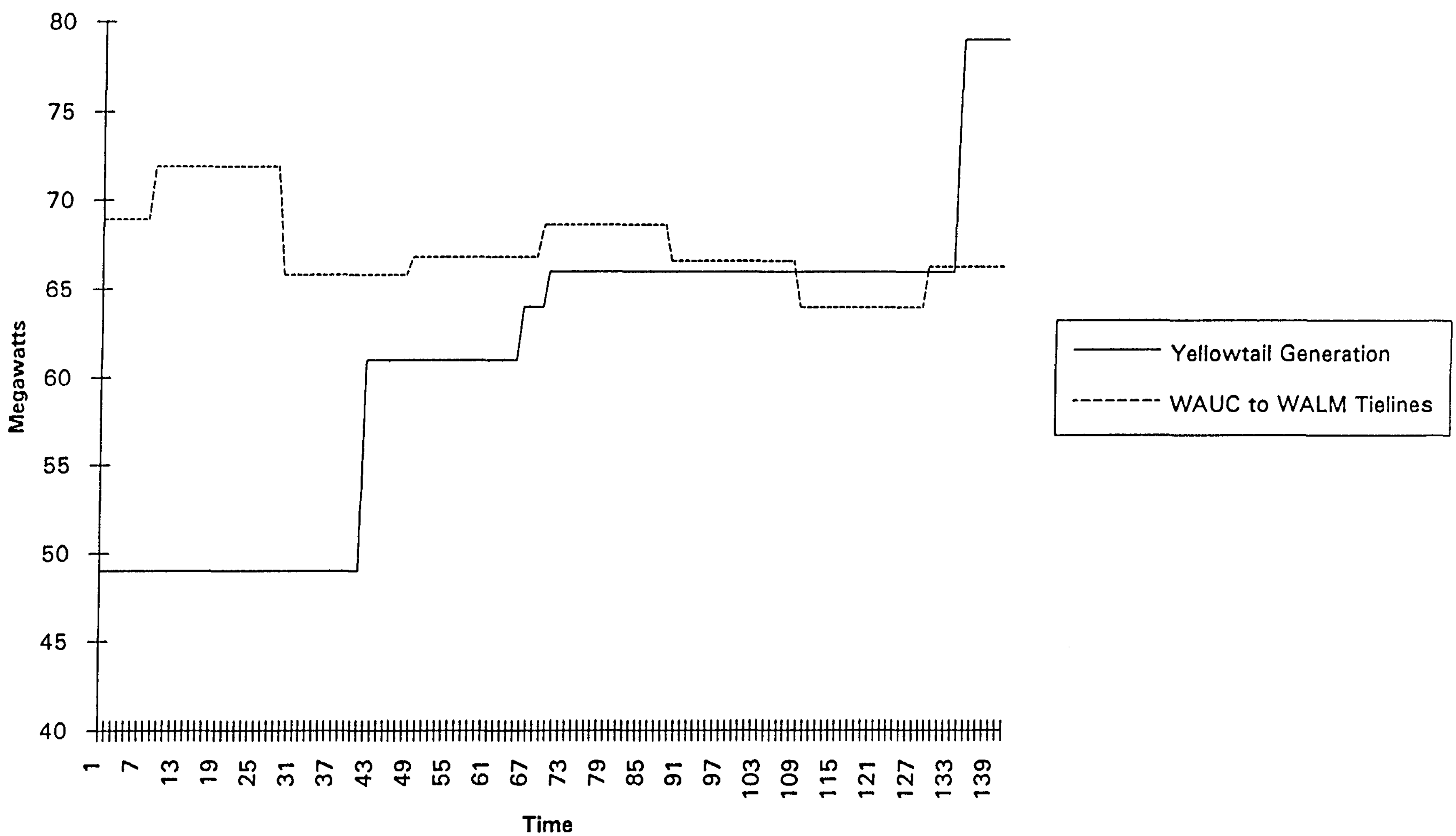


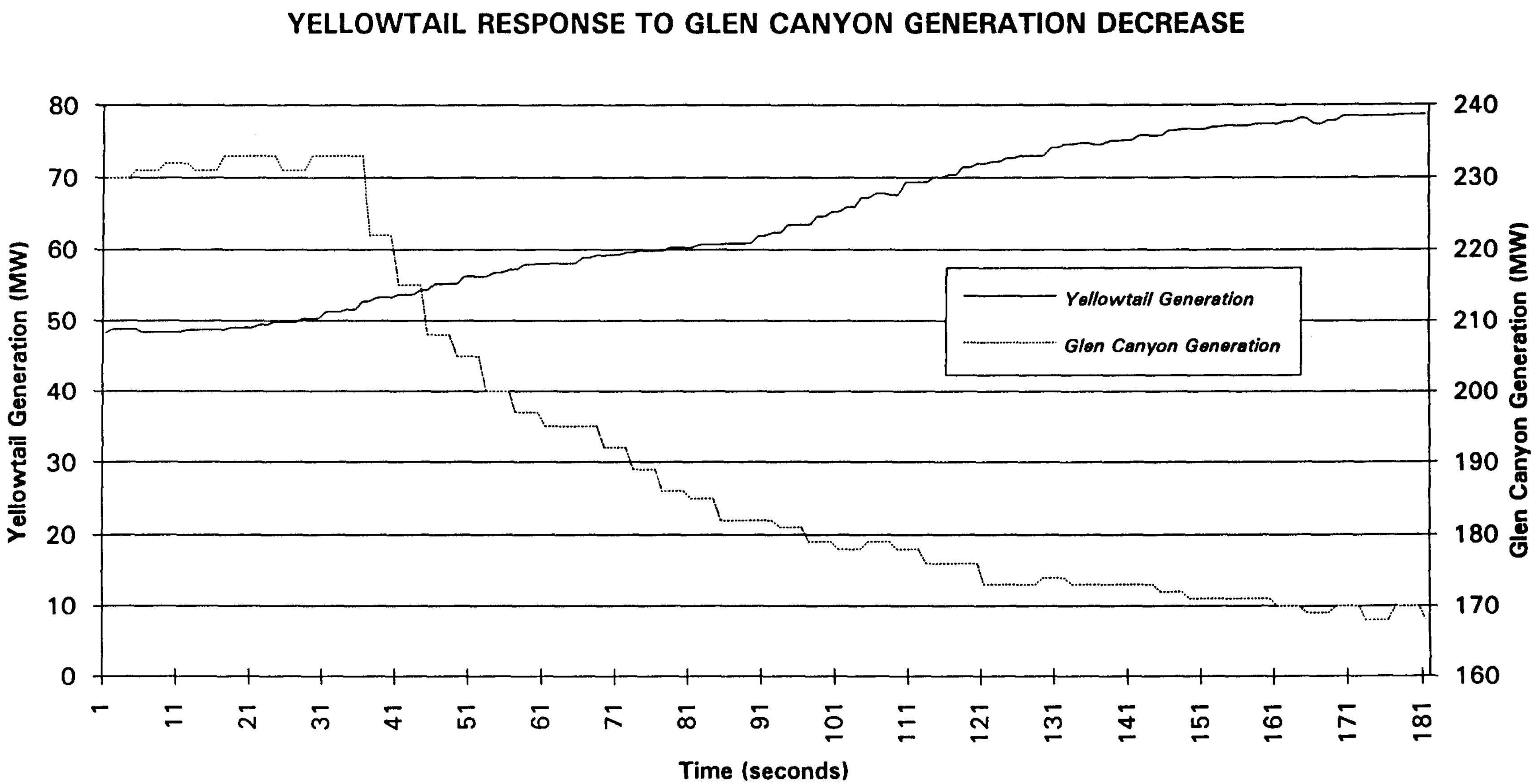
DRPGC.70 Chart 4



DRPGC.70 Chart 9

Yellowtail Generation Control During Glen Canyon Manual Generation Decrease




YELLOWTAIL RESPONSE TO GLEN CANYON GENERATION DECREASE
Yellowtail Generation (MW)
Glen Canyon Generation (MW)
Time (seconds)
Yellowtail Generation
Glen Canyon Generation
80
70
60
50
40
30
20
10
0
240
230
220
210
200
190
180
170
160
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181

APPENDIX B

Initial Model and Simulation

LABORATORY MODEL

The following models were constructed using a digital software simulation package running on a Sun Sparc Station. Two models were constructed, both of which model the AGC generation in the two separate portions of WACM (WALM - Loveland and WAUC - Montrose) as a single unit. Each unit has a 50-second speed level motor modeled with a 28-second plant time constant. Generation not under control and internal loads for both areas are modeled separately. The "Delta" for the WALM control area is also modeled. The first model uses the same gain for raise and lower on the "AGC generation." A step increase in the Page internal load is modeled. The trend charts show the following five channels of data:

1 - WALM (Negative) ACE
2 - WALM "Delta"
3 - WALM (Yellowtail) AGC Generation
4 - WACM (Negative) ACE
5 - WACM Tielines

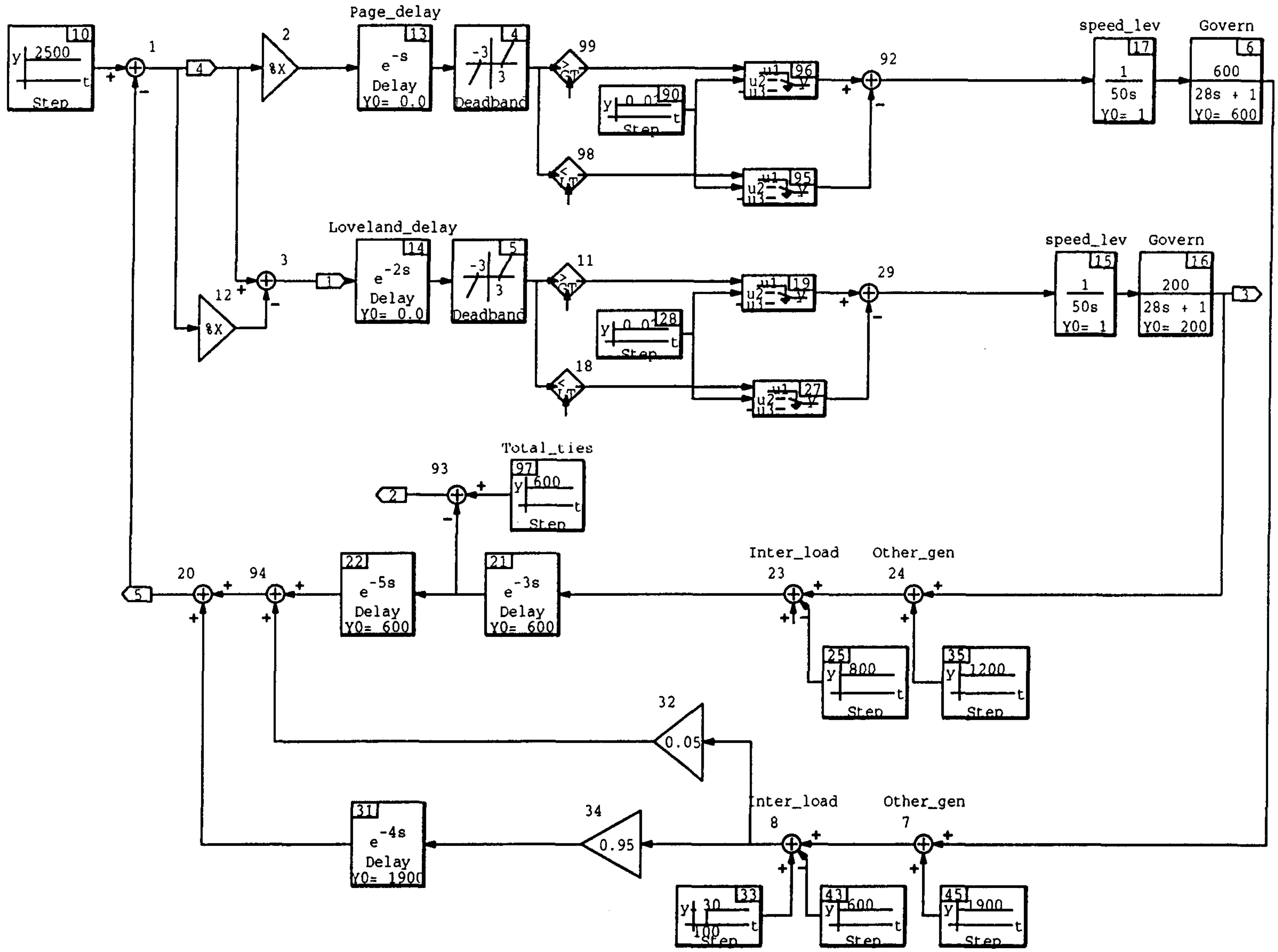
The second page shows a trend chart of the step response. The step change simulates a load decrease in the WAUC portion of the system. As WALM AGC generation participates in this change by unloading, the "Delta" increases. This increase implies that WALM is not meeting its schedule. The response was set to have ACE cross zero in about 120 seconds.

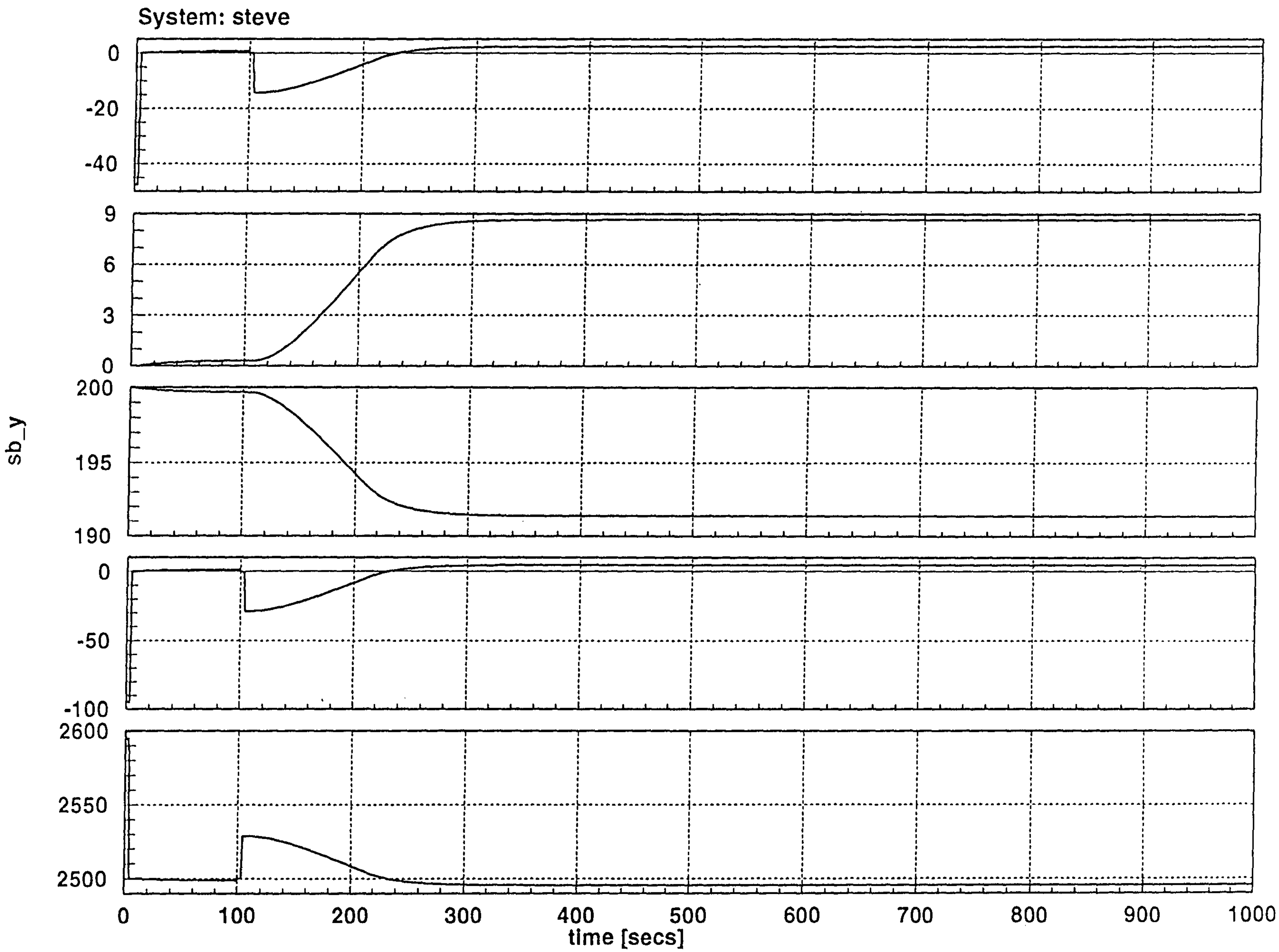
The third page shows the second model with a dual gain used to simulate different raise and lower rates at the powerplant. The gain is higher in the lower direction for WALM (Yellowtail) generation and higher in the raise direction for WAUC (Glen Canyon) generation. A sine wave is use to simulate internal load changes on the WALM system.

The fourth page shows the trend chart of the second model response. As expected, the ACE continually crosses zero; however, the WALM (Yellowtail) generation drifts downward, which causes a similar increasing drift in the "Delta."

20-JAN-94

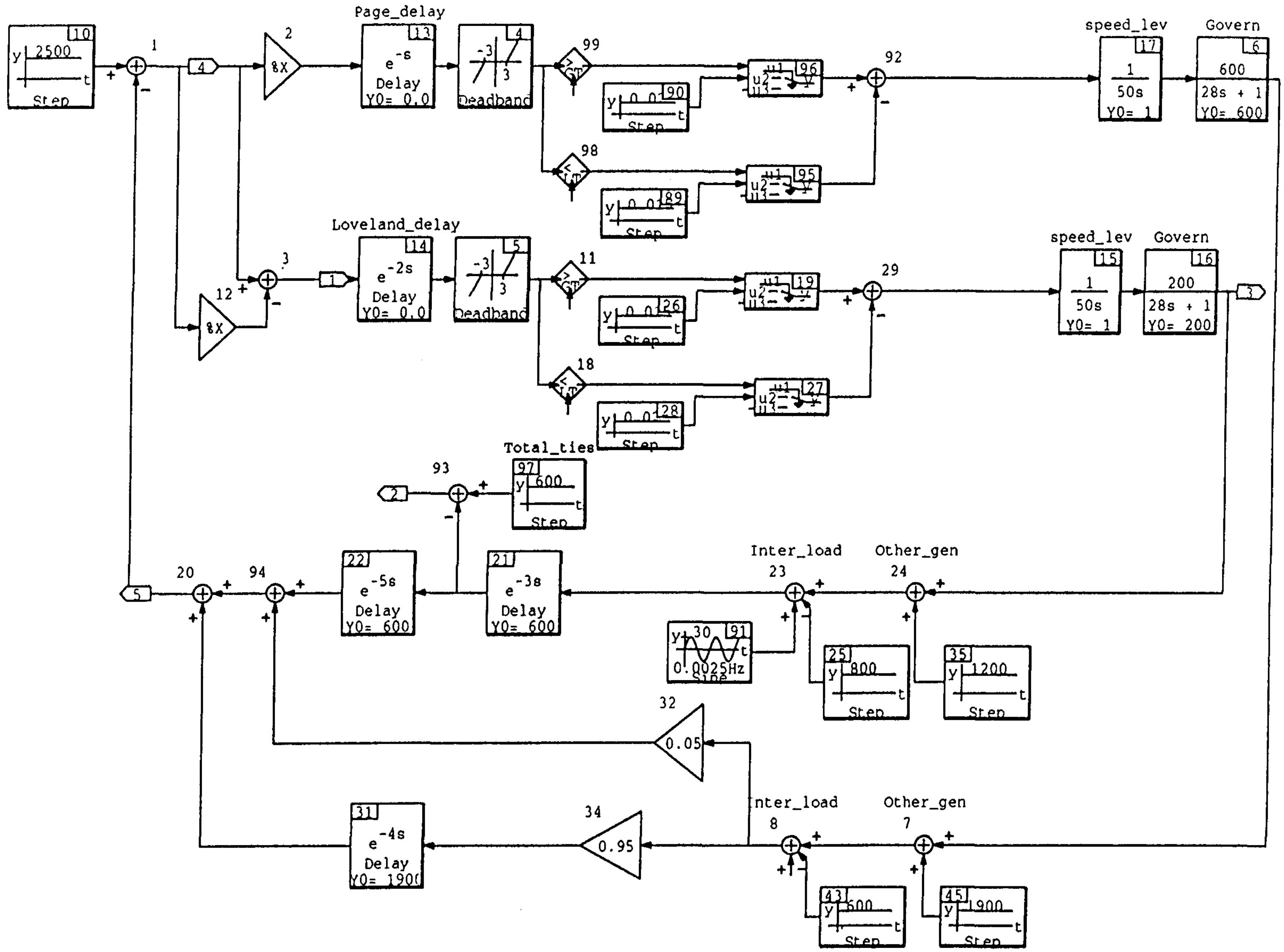
Continuous SuperBlock	Ext.Inputs	Ext.Outputs
steve	0	5

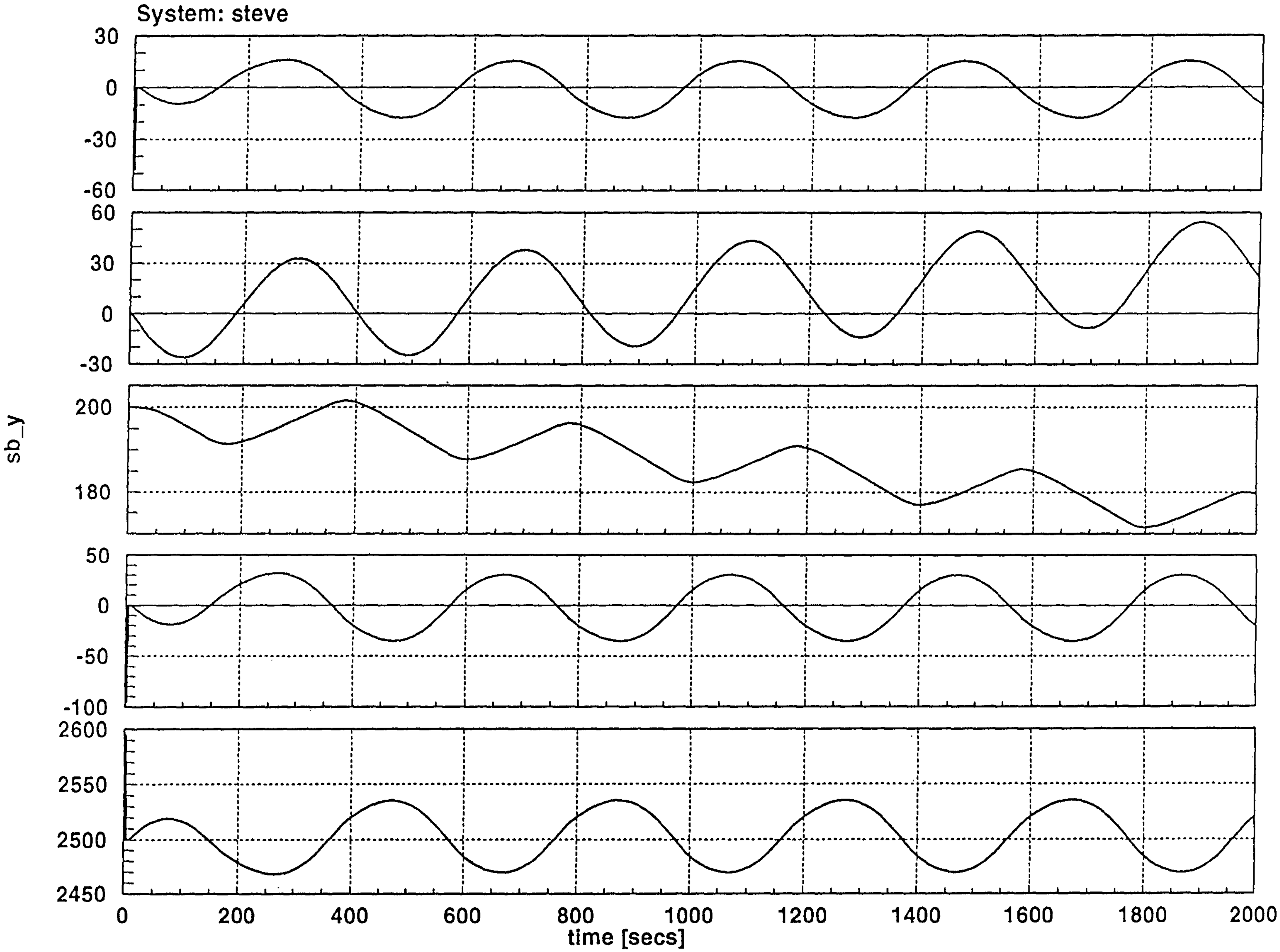



System: steve
0
-20
-40
9
6
3
0
200
195
190
sb_y
0
-50
-100
2600
2550
2500
0
100
200
300
400
500
600
700
800
900
1000
time [secs]

14-DEC-93

Continuous SuperBlock	Ext.Inputs	Ext.Outputs
steve	0	5




System: steve
sb_y
30
0
-30
-60
60
30
0
-30
200
180
50
0
-50
-100
2600
2550
2500
2450
0
200
400
600
800
1000
1200
1400
1600
1800
2000
time [secs]

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.