System Impact Study (Second Study) for Generation Interconnection

Requested by
>Omitted Text>

SPP Coordinated Planning
Request # GEN-2001-026

August 15, 2002

EXECUTIVE SUMMARY

>Omitted Text< has requested interconnection of a 149 MW wind generation facility (Project) to be located in Kiowa, Caddo, and Comanche Counties of southwestern Oklahoma. A feasibility Study was performed at the request of >Omitted Text< in August 2001. On August 31, 2001 >Omitted Text< signed an agreement for a System Impact Study to be performed by Southwest Power Pool (SPP). That study was conducted by SPP and a report issued in January 2002. The basis of that study was for the Project to interconnect to the Western Farmers Electric Cooperative (WFEC) system at a point on the Anadarko-Paradise 138 kV line just north of the Paradise Substation. The Project's expected in-service date was October 2002.

As a result of the System Impact Study reported in January 2002, >Omitted Text< requested a new System Impact Study for a different point of interconnection. The revised point of interconnection is at the 138 kV bus of WFEC's Washita Substation. The Project will build a 19 mile radial 138 kV line to the point of interconnection at Washita. This report presents the results of this new System Interconnection Study.

With the new interconnection point, no thermal limitations were found to be caused by the Project for its full output under all single contingency possibilities within SPP.

Dynamic stability tests found that the Project was unstable for loss of the Washita to Anadarko 138 kV line under full 149 MW Project output conditions. Subsequent tests found that an upper limit on Project output that would remain stable was at 125 MW.

WFEC does not operate its system with the intent that under breaker failure situations all its machines must maintain stability. Therefore, only limited breaker failure tests were conducted.

Short circuit analysis indicated that no existing equipment has its fault interrupting capabilities exceeded as a result of the Project's addition.

It should be noted that this study is not a study of available transmission study (ATC), and should not be so construed. The customer must request transmission service through the SPP OASIS in order to transport power from the facility.

The total cost of the 19 mile radial 138 kV line from the Project to Washita Substation and substation additions at Washita Substation is presently estimated to be $3,770,000. This does not include any tax gross-up.

The lead-time for the interconnection analyzed in this study is 18 months.

Introduction

This is the second System Impact Study conducted for the >Omitted Text< Project, and uses an interconnection plan modified from the first study. The first study was reported in January 2002. In this second System Impact Study the Project is assumed to interconnect to the Western Farmers Electric Cooperative (WFEC) system at its Washita Substation.

The Project is proposed to be a 149 MW windpower project located in Kiowa, Caddo, Comanche Counties of southwestern Oklahoma. It will include a 34/138 kV substation to serve as its high voltage transmission point. From the Project's high voltage substation a 19 mile 138 kV line will be extended to WFEC's Washita Substation. The Project line will interconnect to that substation, requiring the addition of a single 138 kV circuit breaker and related buswork, relaying, and control modifications. A single-line diagram of the 138 kV system in the area of interconnection is shown in Figure 1.

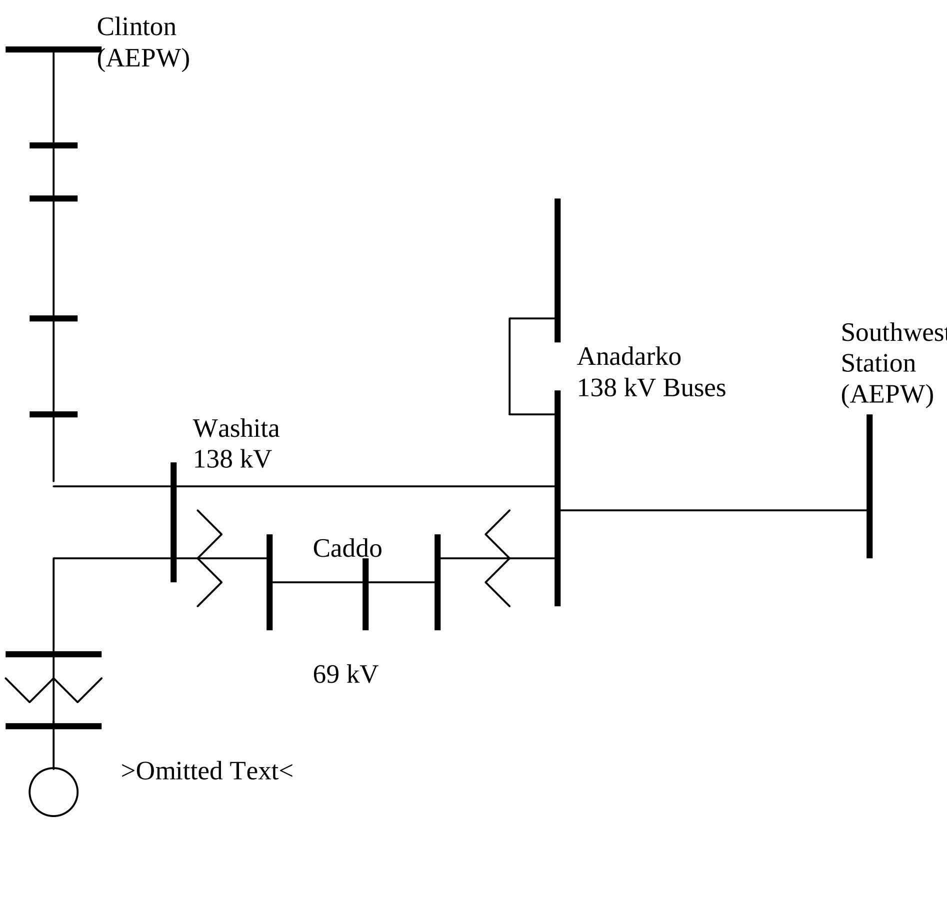


Figure 1 – 138 kV Transmission in Southwestern Oklahoma

The intention of the System Impact Study is to determine the effects of the proposed new generation on the system's performance during normal and contingency conditions.

The Study includes investigation of the Project's effects for steady state, dynamic, and instantaneous (short circuit) conditions under normal operating and defined contingencies. The steady state tests consider thermal overloads and voltage variances. The dynamic analysis tests the ability of the system to maintain the synchronism of all active generators. The instantaneous analysis explores the level of short circuit duty experienced by the system's circuit breakers.

Tests of steady-state as well as short circuit current duty impacts of the Project were conducted at heavy load conditions. Tests of system dynamic performance were conducted at system light load conditions, when the total system level of generator inertia to maintain synchronism is at its minimum. It is assumed that acceptable performance at these two extreme stress conditions for their respective tests will yield acceptable performance under less stressful conditions.

Steady State Analysis

An analysis of the steady state performance of the system was conducted both with and without the Project. The power flow case used was the 2004 Summer Peak Base Case, Update 5, from the 2001 Series. In cases where the Project was operating, generation was reduced at Anadarko and Mooreland in the same total amount that the Project was operated.

The Project is proposed to consist of 99 GE/Enron wind turbine-generators, each of 1.5 MW maximum capability. A 34 kV power gathering system would connect to a 34/138 kV substation, at which point the Project would interconnect to the rest of the system at 138 kV. The maximum Project output proposed by >Omitted Text< is 149 MW. For purposes of this Study the Project was modeled as a single generator operating at 34 kV, with a step-up transformer to 138 kV. From that point a new 138 kV line with impedance and charging to represent a distance of 19 miles was connected to WFEC's Washita Substation. During initial testing to determine the relative level of reactive power required to operate the Project properly, it was found that the Project could operate at relatively high Power Factor, greater than 90%, with acceptable voltage control. Therefore, the Project was modeled as a single generator connected at 34 kV with VAR generation capability of 90% Power Factor lead or lag. Greater definition of the 34 kV power gathering system within the Project was not available, but this approach is considered adequate for extra-Project analysis.

The SPP power flow analysis criteria state that the following conditions must be met:

1. More probable contingency testing…must conclude that
    a. All facility loadings are within their emergency ratings and all voltages within their emergency limits (0.90-1.05 per unit) and

   b. Facility loadings can be returned to within their normal limits within four hours

2. Less probable contingency testing…shall conclude that
   a. Neither uncontrolled islanding, nor uncontrolled loss of large amounts of load will result.

The steady state analysis for normal and more probable contingencies was conducted by using the ACCC function in Power Technologies, Inc.'s PSS/E software. Tests of system normal and all single contingencies within SPP were conducted both with the Project at 149 MW output and with the Project out of service. Then the flow and voltage results were compared against the thermal ratings of the system's lines and transformers. For the thermal impact reviews, the system's normal ratings (Rate A in PSS/E) were used for the system normal test, and the system's emergency ratings (Rate B in PSS/E) were used for the single contingency tests. The range of voltages used as limits were from 90% to 105% of base voltage.

This extensive test showed no system element to be overloaded by the Project's operation, except for certain elements which had pre-existing overloads without the Project in operation.

Testing of less probable contingencies, such as simultaneous loss of two 345 kV lines, or a 345 kV line and a generator, or a line and a transformer were conducted by manually testing individually selected cases. Again, no new system overload was found to be caused by the introduction of the Project to the system.

Thus, it is concluded that for steady state conditions the Project will cause no new overloads within the SPP system by its operation. The connection by the single radial line from the Project to Washita produces no new system overloads under normal or contingency conditions, whereas the previous plan did until augmented by the line now proposed for the interconnection.

It should be noted that the interconnection plan used in this Study is more vulnerable to outage than was the augmented plan in the previous study, since the Project is now proposed to be interconnected by a single radial 138 kV line. The previous study called for two lines from the Project to the rest of the system. The loss of the 138 kV line from the Project to Washita will cause the Project to cease operating, whereas the former plan would still allow full output for loss of either interconnection line. However, since the Project is smaller than the largest generator contingency in the area, this should not require a second line for interconnection.

The base case flow conditions with and without the Project are shown in Figures 2 and 3 at the back of this report.

Transient Stability Analysis

Transient stability analysis was performed to determine the system's dynamic performance. The modeling was conducted using PSS/E's dynamic analysis tools. The system performance analysis was conducted on a spring 2003 light load case, the only light load case available in the SPP current model set. This case, while a full year earlier than the expected Project startup, was deemed sufficiently representative of light load conditions to provide meaningful results. The light load case was selected because this would provide the most severe test of stability on the system, a condition with minimum generation and very low total system inertia and synchronizing capability.

The Project was modeled using a machine model provided out of a joint model development undertaken by GE and PTI to represent the GE/Enron 0.75 MW and 1.50 MW wind turbine-generators. This model uses a well-understood synchronous machine model, GENROU, and a standard exciter model, SEXS, to reflect the fast-acting electronic controls of the machines.[1] Since the machines are DC generators with inverters and electronic controls, it is possible to use these models rather than the induction generator models in early wind development. The report was supplied by >Omitted Text<.

The system interconnection representation for the Project was the same as used in the steady state analysis: a single generator at 34 kV connected to a 34/138 kV transformer and a 138 kV line to Washita. At Washita the bus arrangement is as shown below in Figure 4.

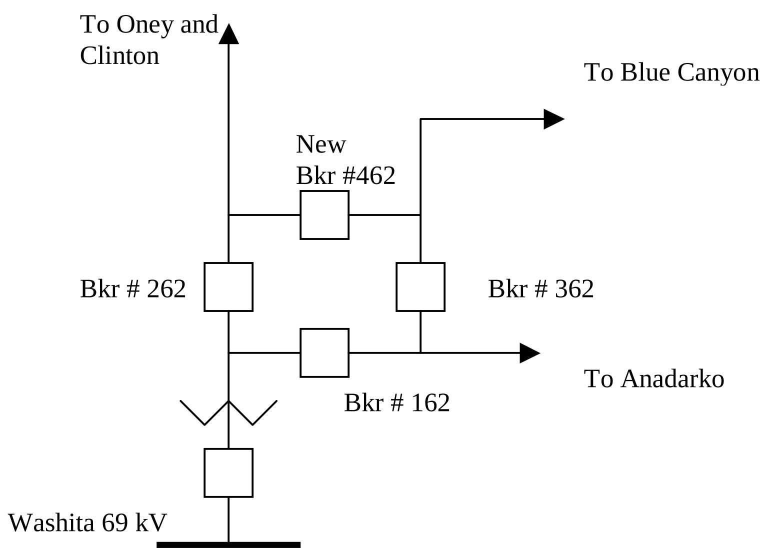


Figure 4 – Washita 138 kV Substation with Project Interconnection

[1] Feltes, Kazachkov and Pillutla, "Development of PSS/E Simulation Models for a Wind Farm, Prepared for Enron Wind Corporation," Power Technologies, Inc., Report R52-00, Sept. 26, 2000.

Tests of stability performance with normal relay and breaker operation were conducted using a total clearing time of 5 cycles. The faults applied were solid three phase ungrounded. No zero sequence network data was included in the stability cases.

For the normal clearing tests a total study time of seven seconds was used. A flat start test was conducted for ten seconds to verify the system's performance without a fault.

All tests but one of normal fault clearing for faults at Washita and Anadarko showed good damping of oscillations and stable performance. The one exception was the loss of the Washita to Anadarko 138 kV line for any reason with the Project at 149 MW output. Even without a fault, the loss of this line caused the Project to exhibit negatively damped oscillations if operating at 149 MW. This negatively damped condition for a fault on the Washita-Anadarko 138 kV line close to Washita is shown in Figure 5 at the back of this report.

Tests were conducted for the most critical fault as noted with gradually decreasing output from the Project until a sufficiently damped oscillatory and stable result was obtained. The output level found to provide this result was 125 MW. The damping at this point is shown in Figure 6.

Options to remediate this limit were developed. The first is to return to the scheme proposed as Option # 4 in the first SIS. The second option is to add a three breaker substation on the Project-Washita 138 kV line at the nearest point to where the line passes AEP West's Southwest Station. At that substation an approximately two mile 138 kV line would be extended to Southwest Station's 138 kV bus and a new breaker added to incorporate this line into Southwest Station. This second option has the advantage of providing a second path between Anadarko and Southwest Stations, and may eliminate the possible need for must-run generation at Anadarko.

The first option was priced in the previous report at a total cost of $5,270,000 without tax gross-up. The second option has not been priced.

Tests were conducted of the effects on stability of WFEC's standard breaker failure backup protection time of 20 cycles. These tests were conducted using single line to ground faults and the Project at an output of 125 MW. The single line to ground impedance to use in the positive sequence network for stability analysis was found from the SPP 2005 sequence data file. In all cases the generators at the Project and Anadarko were unstable.

With backup protection operation at Washita, only two scenarios would allow continued operation of the Project, if a suitable clearing time were implemented, since the other two scenarios would remove the Project anyway. These two possible scenarios are for backup protection operation for failure of breakers 162 and 262, noted in Figure 4.

By gradually moving the clearing time forward a stable condition for the fault, outage, and failure of breaker 262 was found. This was at a critical clearing time of 12 cycles or less. No reasonably achievable critical clearing time for backup protection was found for breaker 162. It is assumed that WFEC will continue its policy of not seeking to maintain stability under breaker failure conditions but to use the delayed clearing to protect equipment from damage. With this approach, only the Project and Anadarko would be tripped, but not Southwest Station, which would remain stable. This meets the SPP criteria.

Short Circuit Analysis

Analysis of the instantaneous fault duties that would be experienced by circuit breakers in the western Oklahoma portion of the SPP system was prepared previously by WFEC. The results were presented in the first System Interconnection Study. This analysis was not repeated in this Study since the fault contributions from the Project would be nearly identical to those in the first Study. It was found in the first study that the Project would not cause any of the breakers in the area to exceed their ratings.

Interconnection Facilities and Costs

The transmission additions and their costs to interconnect the >Omitted Text<Project are:

	Description	Cost
1.	New 19 mile 138 kV transmission line from Project to Washita Substation with 795 MCM wire	$3,420,000
2.	New 138 kV line terminal, breaker position and controls at Washita Substation	350,000
	Total	$3,770,000

Conclusions

The >Omitted Text< Project can be interconnected to the SPP system with a maximum output limited to 125 MW under the proposed interconnection scheme. This limit is set by the transient stability capability of the system. If >Omitted Text< were to install the Project with its full 99 machines, it would have to establish output limiters in its control systems that would assure SPP that its maximum output would be held to 125 MW.

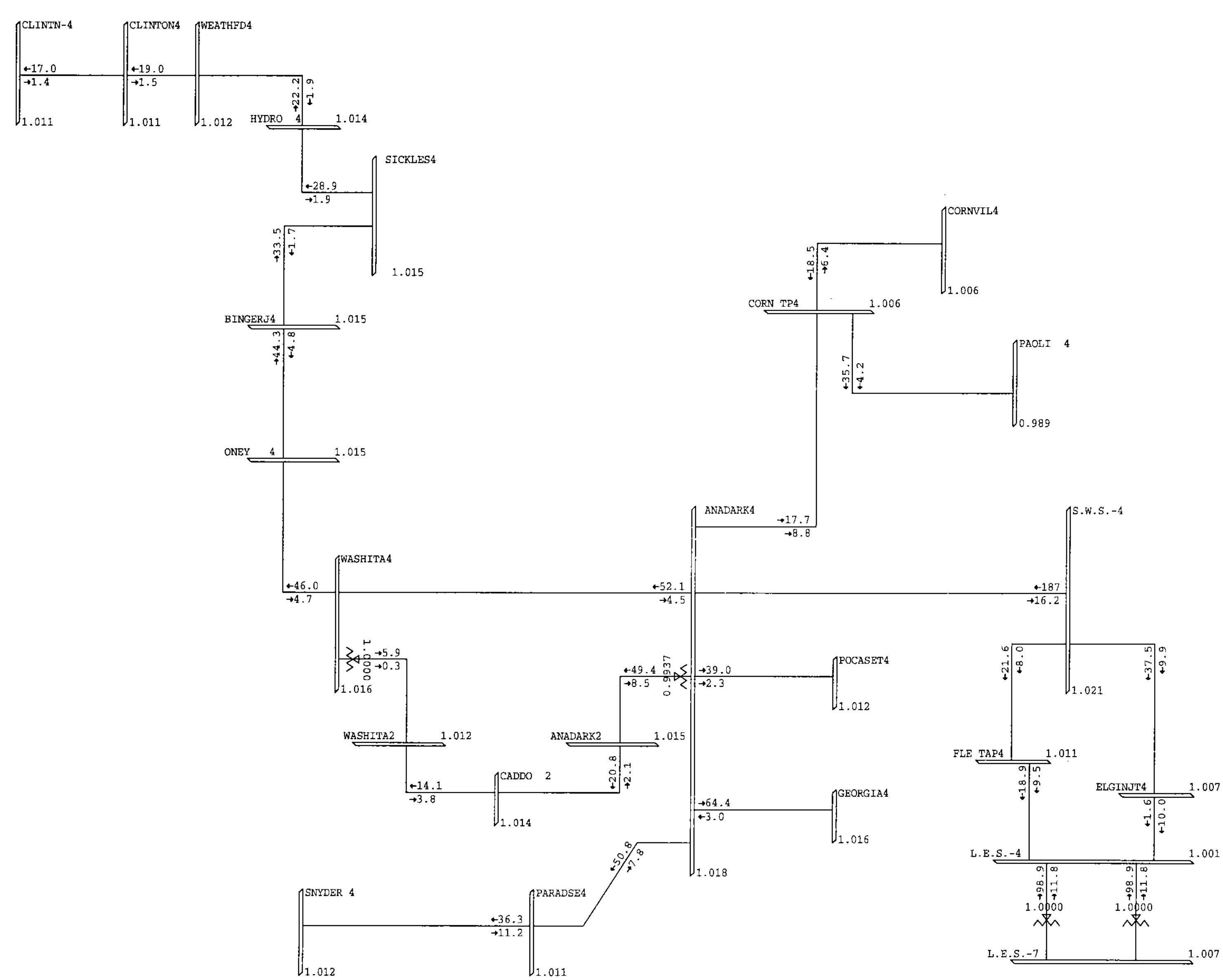
The estimated cost of the system interconnection facilities as proposed is $3,770,000. This does not include any tax gross-up.

Two possible system additions have been developed that would remove the limit on output, either of which would be effective. The first is to build a 138 kV line from the Project to the Anadarko-Paradise line and add a switching station at that point. This is the recommended option for Project interconnection from the first SIS, and has a total cost of $5,270,000 without any tax gross-up. The second possible addition would be to build a 138 kV line from the nearest point on the Project-Washita line to Southwest Station, with associated switching station and interconnection at Southwest Station. This option has not been estimated for cost. Both possible additions would provide at least the capability to interconnect the Project at its full 149 MW output.

The interconnection scheme(s) and the associated costs are those required for Project interconnection only. The level and cost of transmission service are determined by separate studies if >Omitted Text< requests transmission service through SPP's OASIS.

Appendix A
Figures 2 and 3

Figure 2



2001 SPP POWER FLOW MODEL 2004 SUMMER PEAK (04SP) BASE CASE BASE CONDITIONS FOR [redacted] INTERCONNECTION STUDY BASE CASE WITHOUT PROJECT THU, AUG 15 2002 13:08	BUS - VOLTAGE(PU) BRANCH - MW/MVAR EQUIPMENT - MW/MVAR

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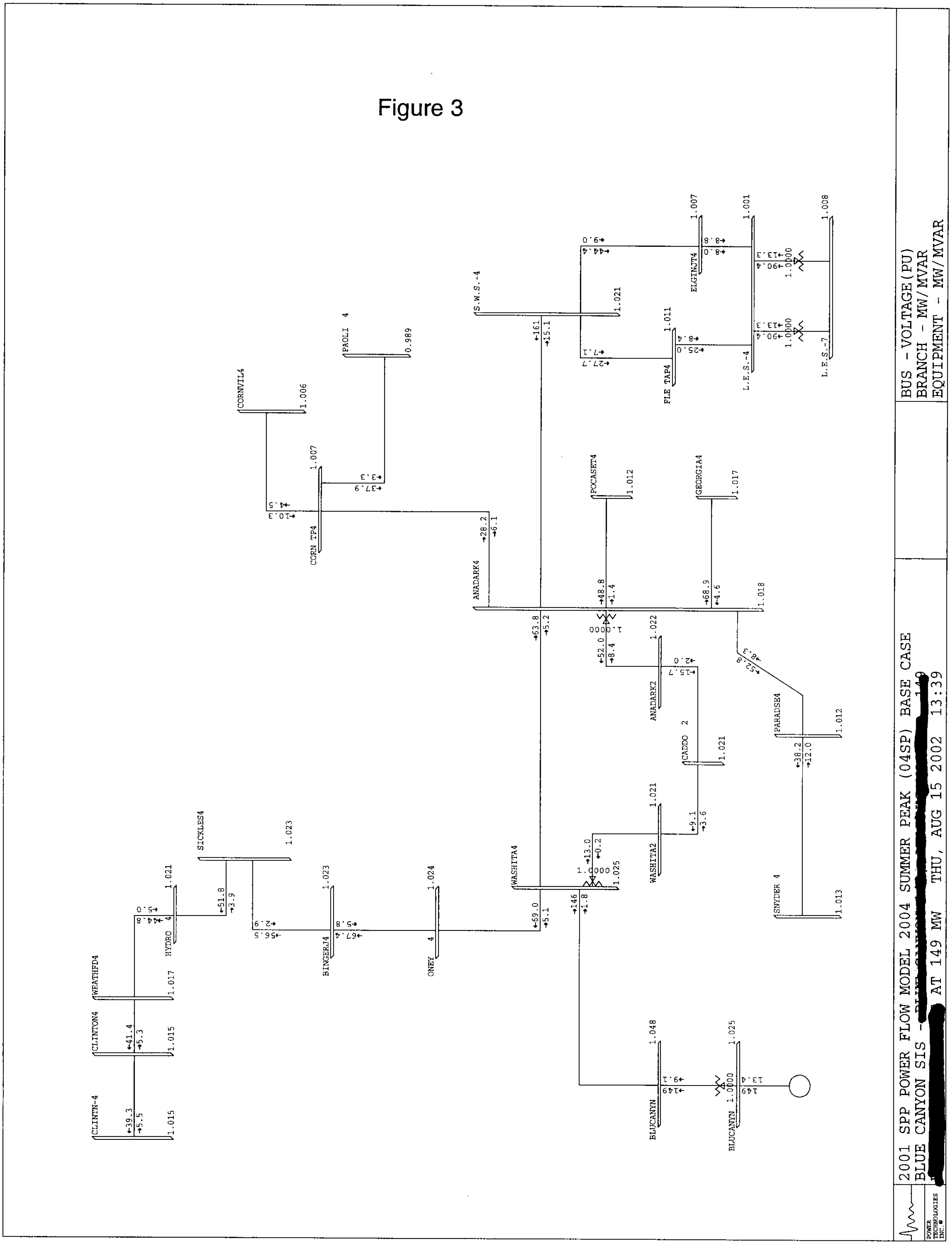
Figure 3


2001 SPP POWER FLOW MODEL 2004 SUMMER PEAK (04SP) BASE CASE
BLUE CANYON SIS - [redacted] AT 149 MW THU, AUG 15 2002 13:39
BUS - VOLTAGE(PU)
BRANCH - MW/MVAR
EQUIPMENT - MW/MVAR
POWER TECHNOLOGIES INC.
CLINTN-4
CLINTON4
WEATHFD4
HYDRO 4
SICKLES4
BINGERJ4
ONEY 4
WASHITA4
WASHITA2
BLUCANYN
CADDO 2
ANADARK2
ANADARK4
PARADSE4
SNYDER 4
POCASET4
GEORGIA4
CORN TP4
CORNVIL4
PAOLI 4
S.W.S.-4
FLE TAP4
ELGINJT4
L.E.S.-4
L.E.S.-7

Appendix B

Transient Stability Study
Details and Diagrams

Stability Simulation Basis

- 3 phase fault cleared in 5 cycles
- Swing curve title shows faulted line end first
- All swing curves allowed to run 7 seconds
- For reduced Project generation, output level is shown in the title. Otherwise, output is 149 MW

Breaker Failure Scenarios at Washita

Failure on Breaker No.	Line/Transformer Removed by Backup Protection
162	Washita – Anadarko Washita 138/69 kV transformer
262	Washita – Oney Washita 138/69 kV transformer
362	Washita – >Omitted Text< Washita – Anadarko
462 (new)	Washita – >Omitted Text< Washita - Oney

Simulation Cases

	Description	Result
1.	Washita – Oney 138 kV line	Stable
2.	Washita 138/69 kV transformer	Stable
3.	Anadarko – Southwest Station 138 kV line	Stable
4.	Washita – Anadarko 138 kV line, >Omitted Text<149 MW	Negative Damping
5.	Anadarko - Washita 138 kV line, >Omitted Text<149 MW	Negative Damping
6.	Washita – Anadarko 138 kV line, >Omitted Text<135 MW	Poorly Damped
7.	Washita – Anadarko 138 kV line, >Omitted Text<125 MW	Satisfactory Damping
8.	Washita Breaker # 262 failure, >Omitted Text<125 MW, 12 cycle total clearing time	Stable

2002 SPP POWER FLOW MODEL (JAN 2002)2003 APRIL MIN UPDATE 5
PROJECT 2001-26 AT 125 MW

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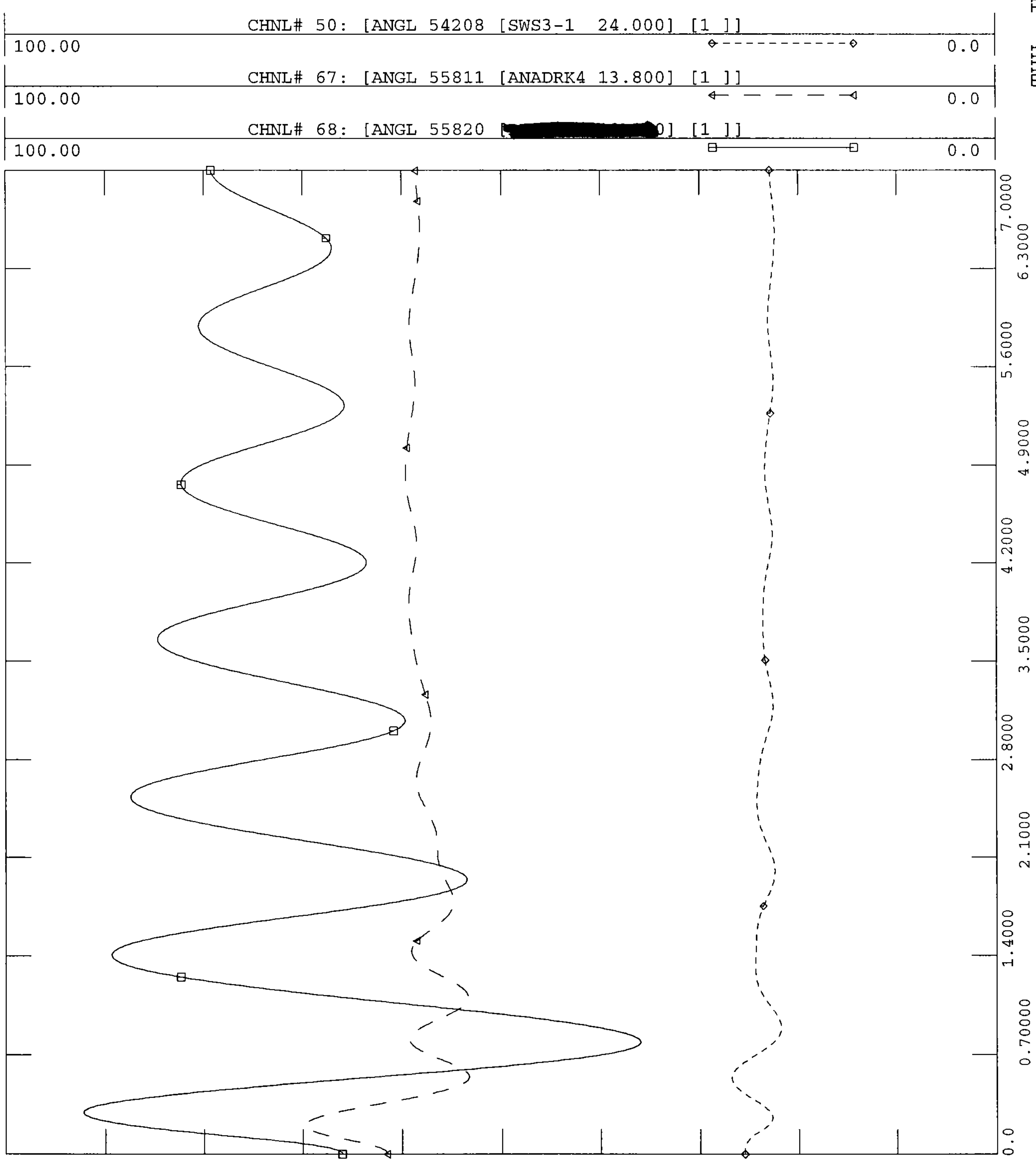
THU, JUL 11 2002 9:02

125 WASHITA-ANDRKO NORMAL



2002 SPP POWER FLOW MODEL (JAN 2002)2003 APRIL MIN UPDATE 5
PROJECT 2001-26 AT 125 MW

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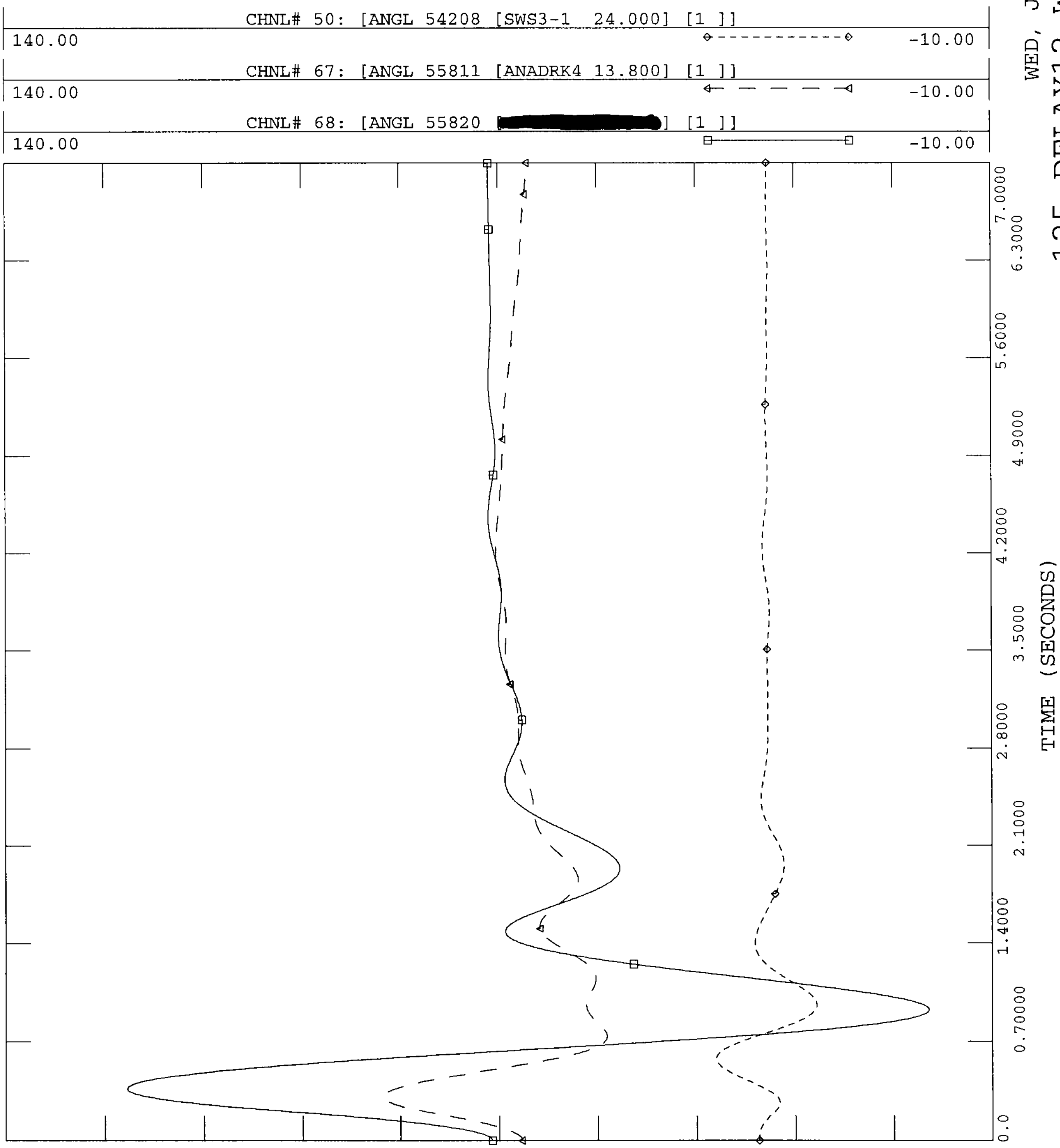
125 DELAY12 WASH BKR 262



2002 SPP POWER FLOW MODEL (JAN 2002)2003 APRIL MIN UPDATE 5
PROJECT 2001-26 AT 135 MW

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MON, JUL 15 2002 10:26

135 WASH-ANDRKO NORMAL

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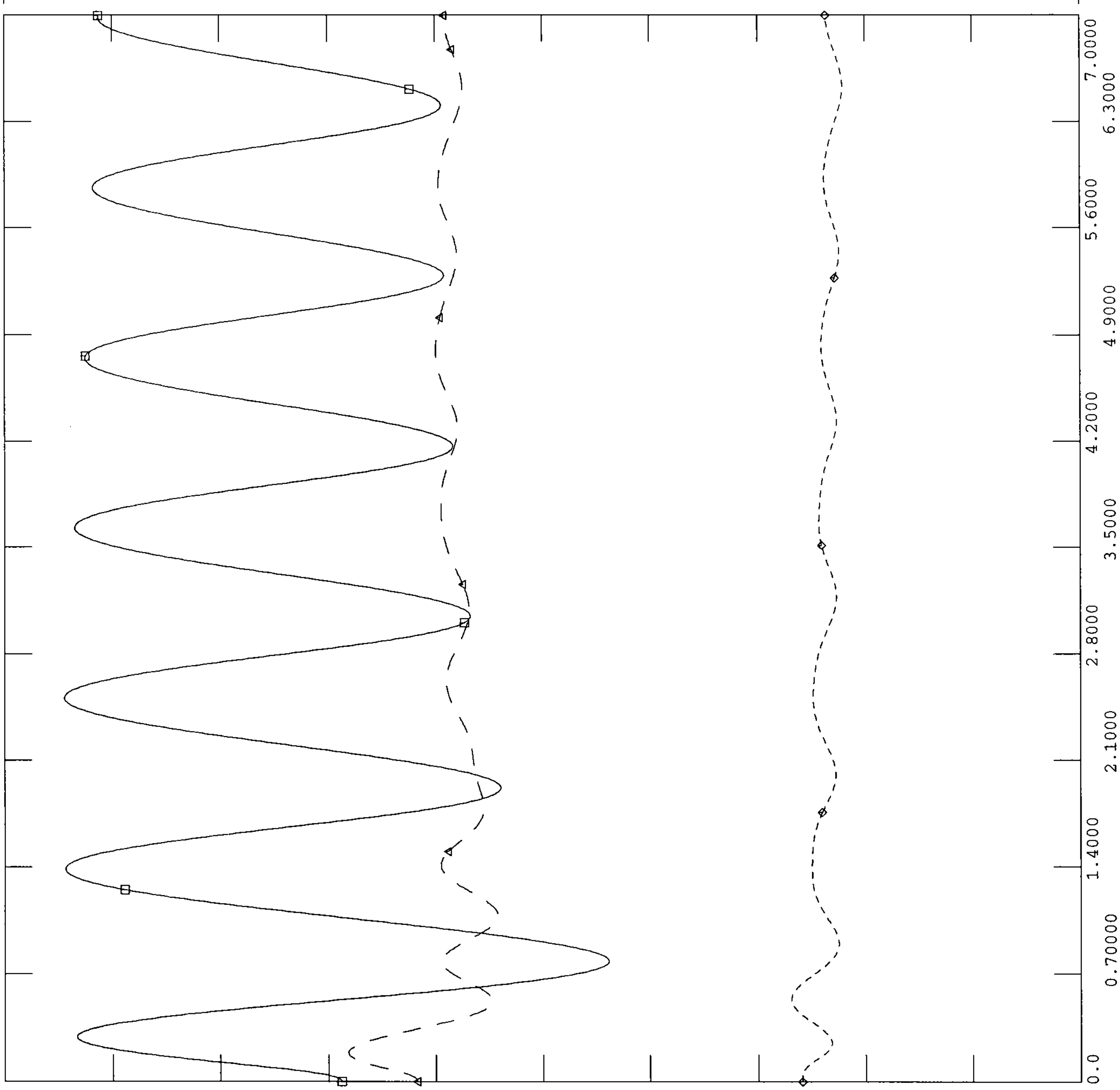

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2002 SPP POWER FLOW MODEL (JAN 2002)2003 APRIL MIN UPDATE 5
PROJECT 2001-26 AT 149.5 MW

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ANADARKO-SWS NORMAL

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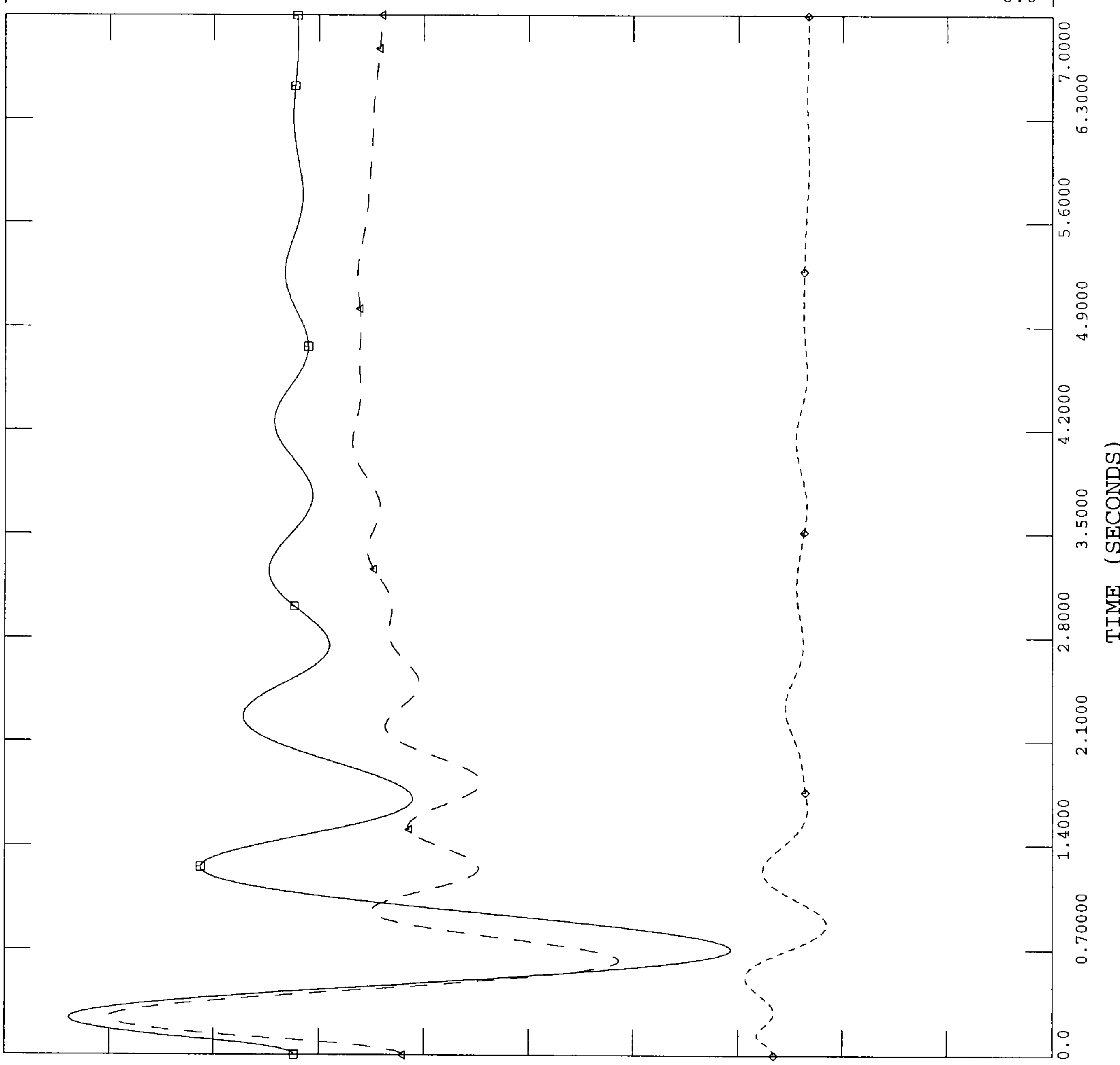

2002 SPP POWER FLOW MODEL (JAN 2002)2003 APRIL MIN UPDATE 5
PROJECT 2001-26 AT 149.5 MW

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WASH 138/69XFMR NORMAL

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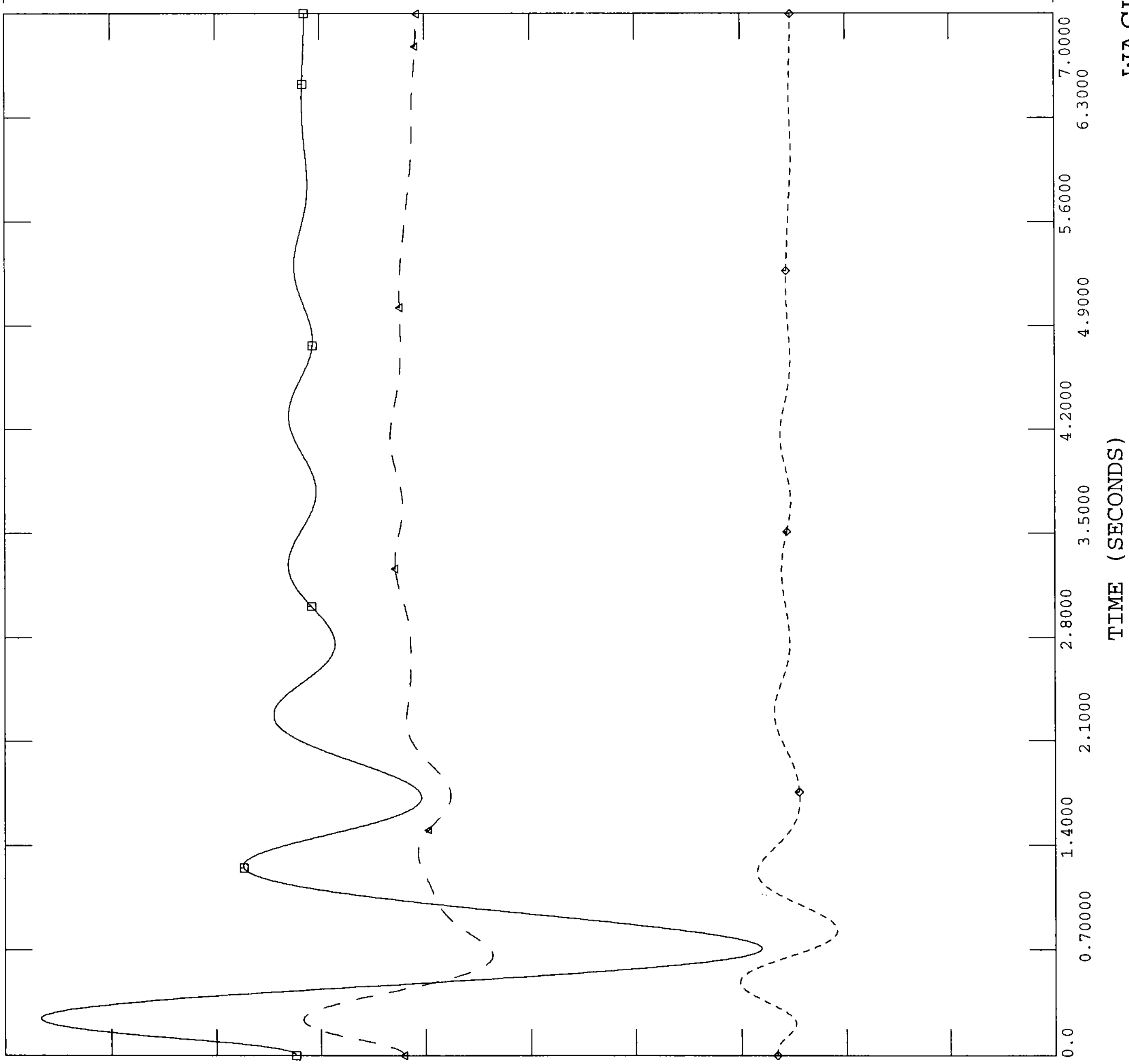

2002 SPP POWER FLOW MODEL (JAN 2002)2003 APRIL MIN UPDATE 5
PROJECT 2001-26 AT 149.5 MW

POWER TECHNOLOGIES INC.©

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WASH-ANADARKO-NORMAL CLEAR

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	CHNL# 67: [ANGL 55811 [ANADRK4 13.800] [1]]	
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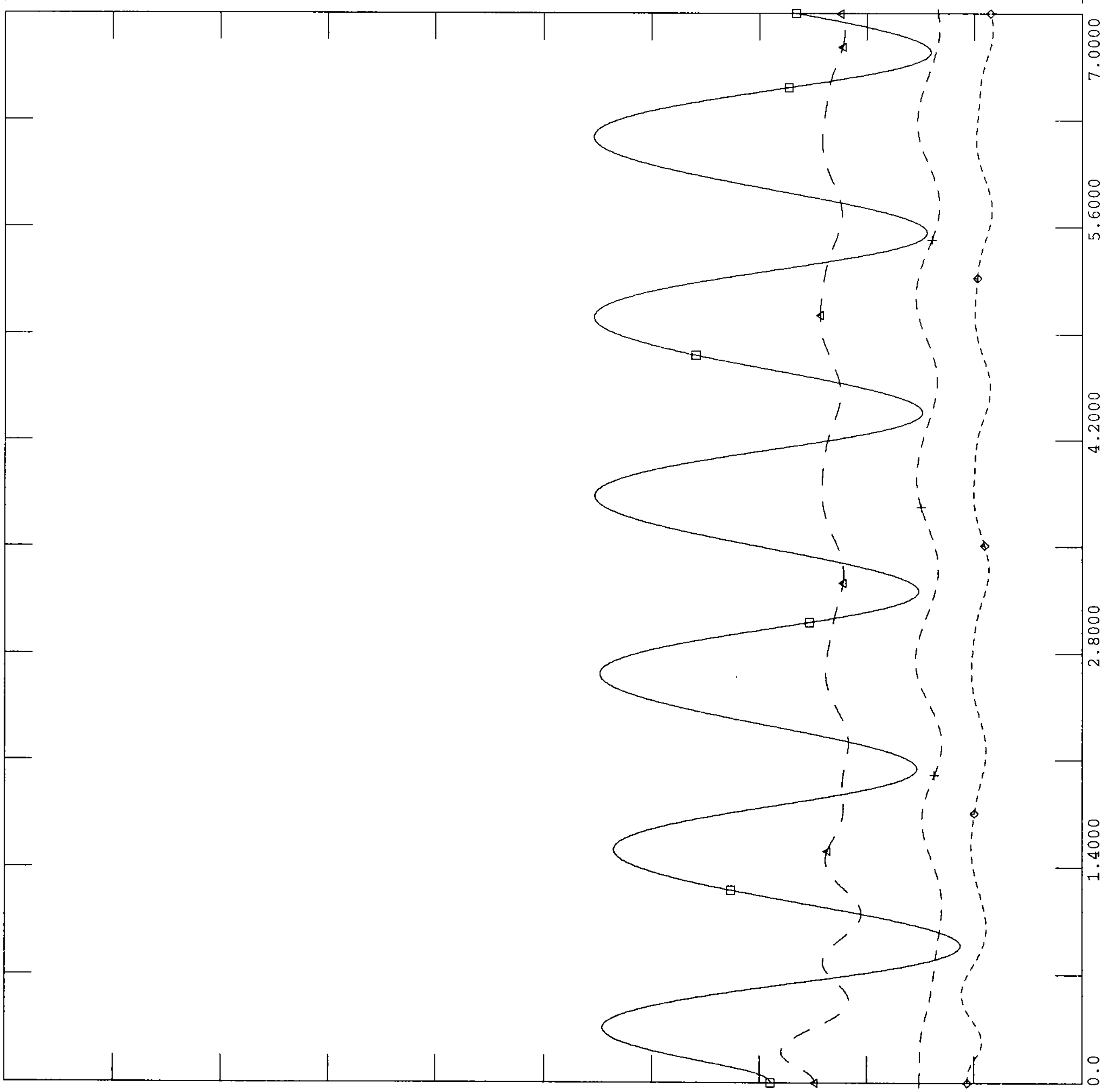

2002 SPP POWER FLOW MODEL (JAN 2002)2003 APRIL MIN UPDATE 5
PROJECT 2001-26 AT 149.5 MW

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WASHITA-ONEY NORMAL