Southwest Power Pool

System Impact Study for Generation Interconnection Request

GEN-2003-009

SPP Tariff Studies
(#GEN-2003-009)

February 2004

Executive Summary

<OMITTED TEXT> (Customer) has requested a System Impact Study under the Southwest Power Pool Open Access Transmission Tariff (OATT) for the purpose of interconnecting up to a 81 MW wind powered generation facility in Carson County, Texas to the transmission system of Southwestern Public Service Company (SPS/Xcel Energy). The wind powered generation facility will be comprised of 54 individual 1.5MW GE 1.5s wind turbines. The planned in-service date for the 81MW facility is Fall 2004. However, this date was considered non-feasible considering the long order and lead times for equipment and construction.

The wind powered generation facility will be located approximately 9 miles west of Panhandle, Texas. The generation facility will interconnect to the Carson County substation via a new, re-configured Carson County 115kV substation. The current Carson County substation is configured as a simple tap on the 115kV line circuit V-60 and is un-able to accommodate the connection of the generation facility. The substation will be re-configured as a full switching station in a configuration to be determined later. The substation configuration will be finalized during the Facility Study if the customer elects to proceed.

There were no adverse impacts to the SPS/Xcel Energy transmission system identified through the power flow and single contingency studies, provided the generation facility satisfies the power factor requirements of SPS/Xcel Energy. Induction generator installations must provide power factor control within a range of 0.95 leading to 0.95 lagging. The Producer must provide any capacitors or other devices needed to achieve this power factor performance level.[1] The GE turbines utilized for this facility have the capability of achieving this power factor requirement. However, it should be noted that the requirement is at the Point of Interconnection and not at the turbines. Losses between the facility and the Point of Interconnection may require additional compensation depending on final siting and equipment configuration.

Using the machine data provided by the requestor and other information publicly available, the stability studies indicate that the SPS/Xcel Energy system will remain stable when the 81MW wind powered generation facility is connected to the transmission system. The GE turbines were able to ride-through the 15 distinct fault simulations that were specified by SPS/Xcel Energy. In early stages of the analysis, the farm would trip due to high voltage at some of the generators, but this was easily corrected by adjusting the transformer ratio settings on the 34.5/115kV transformer.

Short circuit analysis for this wind powered generation facility will be performed by SPS/Xcel Energy as part of the Facility Study if the customer elects to proceed.

The total estimated cost of construction on the SPS/Xcel Energy system for this interconnection is $3.1 million. The cost includes construction and re-configuration of the Carson County substation to accept the generating facility, associated breakers and metering, routing of circuit V-60 into and out of the substation, and right-of-way. It is assumed for purposes of this estimate that the customer 34.5/115kV substation would be located adjacent to the Carson County substation.

1. *Interconnection Guidelines For Transmission Interconnected Producer-Owned Generation Greater Than 20 MW Version 2.0*, p. 24, Retrieved 02/11/2004 from http://www.xcelenergy.com/docs/corpcomm/TransmissionInterconnectionGuidelines.pdf

1. Introduction

<OMITTED TEXT> (Customer) has requested a System Impact Study under the Southwest Power Pool Open Access Transmission Tariff (OATT) for the purpose of interconnecting up to a 81 MW wind powered generation facility in Carson County, Texas to the transmission system of Southwestern Public Service Company (SPS/Xcel Energy). The wind powered generation facility will be comprised of 54 individual 1.5MW GE 1.5s wind turbines. The planned in-service date for the 81MW facility is Fall 2004. However, this date was considered non-feasible considering the long order and lead times for equipment and construction.

The wind powered generation facility will be located approximately 9 miles west of Panhandle, Texas. The generation facility will interconnect to the Carson County substation via a new, re-configured Carson County 115kV substation. The current Carson County substation is configured as a simple tap on the 115kV line circuit V-60 and is not able to accommodate the connection of the generation facility. The substation will be re-configured as a full switching station in a configuration to be determined later. The substation configuration will be finalized during the Facility Study if the customer elects to proceed.

2. Purpose

The purpose of the Interconnection System Impact Study is to evaluate the impact of the proposed interconnection on the reliability of the Transmission System. The Interconnection System Impact Study will consider the Base Case as well as all Generating Facilities (and with respect to (iii) below, any identified Network Upgrades associated with such higher queued interconnection) that, on the date the Interconnection System Impact Study is commenced: (i) are directly interconnected to the Transmission System; (ii) are interconnected to Affected Systems and may have an impact on the Interconnection Request; (iii) have a pending higher queued Interconnection Request to interconnect to the Transmission System; and (iv) have no Queue Position but have executed an LGIA or requested that an unexecuted LGIA be filed with FERC.

There are also several previously queued projects ahead of this request in the SPP Generation Interconnection queue. It was assumed for purposes of this study that not all of those projects would be in-service if this project is built. Any changes to this assumption, i.e. one or more of the previously queued projects not included in the study signing an interconnection agreement, may require a re-study of this request at the expense of the customer.

Nothing in this System Impact Study constitutes a request for transmission service or confers upon the Interconnection Customer any right to receive transmission service.

3.0 Facilities

3.1 Generating Facility

The generating facility is proposed to consist of GE 1.5s wind turbines. The nameplate rating of each turbine is 1.5MW (1500kW) with a machine base of 1667kVA. The turbine output voltage is 575V. The GE turbines utilize a doubly fed induction-generator with a wound rotor and slip rings. The generator synchronous speed is 1200 rpm, and a variable frequency power converter tied to the generator rotor allows the generator to operate at speeds ranging from 800 rpm to 1600 rpm. Nominal speed at 1.5MW power output is 1440 rpm and the maximum allowable non-operating rotational speed is 1680 rpm. The power converter allows the generator to produce power at a power factor of 0.9 lagging to 0.95 leading. The power factor is settable at each WTG or by the Plant SCADA system.

This power converter capability allows the turbines to have a significantly stronger voltage ride-through capability than other turbine models.

3.2 Interconnection Facility

The Customer has proposed constructing an interconnection facility, which would connect to the SPS/Xcel Energy transmission system via the Carson County substation located in Carson County, Texas. The interconnection would be via a re-configuration of the existing Carson County substation to accept a terminal from an adjacent 34.5/115kV transformer substation that serves the wind powered generation facility. The current Carson County substation is only a simple tap on circuit V-60 and is not configured to allow connecting the generation facility. The point of interconnection is defined as the point at which the customer's facilities connect to the new Carson Co. substation. Any facilities on the customer's side of the point of interconnection are the customer's responsibility. Any facilities constructed on the transmission owner's side of the point of interconnection are considered network upgrades.

4.0 Analysis

4.1 Powerflow Analysis

A powerflow analysis was conducted for the facility using a modified version of the 2009 Summer Peak model. The output of the Customer's facility was offset in each model by a reduction in output of existing online SWPS generation. The in-service date of the facility is proposed to be October 2004. However, considering equipment purchase times and construction times for the substation, the October 2004 in-service date was considered non-feasible. The next available seasonal model for use was the 2009 Summer Peak. This is the end of the current SPP planning horizon.

The analysis of the customer's project shows that the proposed location can handle the entire 81MW of output under steady state conditions without system upgrades in all seasons out to the end of SPP's planning horizon.

There are several other proposed wind generation additions in the general area of the Customer's facility. It was assumed in the analysis that not all of these other projects were in service. Those previously queued projects that have advanced to nearly complete phases were included in this System Impact study.

4.1.1 Powerflow Analysis Methodology

The Southwest Power Pool (SPP) criteria states that: The transmission system of the SPP region shall be planned and constructed so that the contingencies as set forth in the Criteria will meet the applicable *NERC Planning Standards* for System Adequacy and Security – Transmission System Table I hereafter referred to as NERC Table I) and its applicable standards and measurements.

Using the created models and the ACCC function of PSS\E, single contingencies in the SWPS control area were applied and the resulting scenarios analyzed. This satisfies the 'more probable' contingency testing criteria mandated by NERC and the SPP criteria.

4.2 Stability Analysis

A 2009 Summer Peak stability case was used to analyze the effects of various transmission system faults on the wind farm and the resulting effects of the wind farm response to the system.

The faults that were performed were defined by SPS and are as follows:

1. FLT13PH – 3-phase fault

Fault on the Nichols (50915) – Grapevine (50827), 230kV line, near Nichols.

a. Apply Fault at the midpoint of the line.
b. Clear Fault after 5 cycles by removing the line from 50915 - 50827.
c. Wait 20 cycles, and then re-close the line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

2. FLT21PH – 1-phase fault

?? Same as FLT13PH above.

3. FLT33PH – 3-phase fault

Fault on the Grapevine (50827) – Elk City (54153) 230kV line, near Elk City.

a. Apply fault at the Elk City bus (54153).
b. Clear fault after 5 cycles by removing the line from 50827 – 54153.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

4. FLT41PH – 1-phase fault

?? Same as FLT33PH above.

5. FLT53PH – 3-phase fault

Fault on the Nichols (50914) – Kirby (50932) 115kV line, near Kirby.

a. Apply fault at the Kirby bus (50932).
b. Clear fault after 5 cycles by removing the lines:
    i. Kirby (50932) – Conway (50928),
    ii. Conway (50928) – Yarnell (50926) and
    iii. Yarnell (50926) – Nichols (50914).
c. Wait 20 cycles, and then re-close lines in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

6. FLT61PH – 1-phase fault

?? Same as FLT53PH above.

7. FLT_7_3PH – 3-phase fault

Fault on the Potter County (50888) – Finney Switch Station (50838) 345kV line, near Finney.

a. Apply fault at the Finney bus (50858)
b. Clear fault after 5 cycles by removing the line from 50888 to 50858.
c. Wait 30 cycles, and then re-close the line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove the fault.

8. FLT_8_3PH – 3-phase fault

Fault on the Bushland Interchange (50993) – Potter County (50887) 230kV line, near Potter County.

a. Apply fault at the Potter County bus (50887).
b. Clear fault after 5 cycles by removing line from 50887 to 50993.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

9. FLT_9_1PH – 1-phase fault

?? Same as FLT_8_3PH above.

10. FLT_10_3PH – 3-phase fault

Fault on the Hutchinson Co. Interchange (50750) – Riverview Interchange (50694) 115kV line, near Hutchinson Co.

a. Apply fault at the Hutchinson County bus (50750).
b. Clear fault after 5 cycles by removing line from 50750 to 50694.
c. Wait 20 cycles, and then re-close line in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

11. FLT_11_1PH – 1-phase fault

?? Same as FLT_10_3PH above.

12. FLT_12_3PH – 3-phase fault

Fault on the Moore County (50664) – Riverview (50694) 115kV line, near Moore County.

a. Apply fault at the Moore County 115kV bus (50664).
b. Clear fault after 5 cycles by removing the lines:
    iv. Moore County (50664) – R.B. Sneed (50690),
    v. R.B. Sneed (50690) – Herring Tap (50686) and
    vi. Herring Tap (50686) – Riverview (50694).
c. Wait 20 cycles, and then re-close lines in (b) into the fault.
d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

13. FLT_13_1PH – 1-phase fault

?? Same as FLT_12_3PH above.

14. FLT_14_3PH – 3-phase fault

Fault on the Wolfforth Interchange (51762) – Terry County (51830) 115kV line, near Terry County.

b. Apply fault at the Terry County bus (51830).
c. Clear Fault after 5 cycles by removing line from 51762 – 51830.
d. Wait 20 cycles, and then re-close line in (b) into the fault.
e. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

15. FLT_15_1PH – 1-phase fault

?? Same as FLT_14_3PH above.

The above cases were run for the following conditions:

System base case with Wind farm idled (0MW)
Wind farm output at 81MW with power factor control enabled (PF set to 0.98 lag)
Wind farm output at 81MW with voltage control enabled
Wind farm output at 40.5 MW with voltage control enabled

4.2.1 Dynamic Modeling of the Wind Powered Generation Facility

The rated output of the generation facility is 81MW, comprised of fifty-four (54) GE 1.5s wind turbines. The base voltage of the GE turbine is 575 V, and a generator step up transformer (GSU) of 1.75MVA connects each unit to the high side of 34.5kV. The rated power output of each turbine is 1.5MW while the actual power output depends on the wind.

In performing a system impact study, existing on-line generation in the local control area is displaced by the addition of the generator in order to preserve control area interchange schedules in the model. Adjustment of the control area dispatch is performed with input from the Transmission Owner to accurately model unit commitments and availability.

The generating facility substation will consist of three (3) 42MVA 115kV/34.5kV transformers connected in parallel. From the preliminary one-lines received from the customer, on the 34.5kV side of each transformer, two feeder circuits will extend into the generating facility. Each feeder will consist of 9 turbines. Each turbine then has its own pad-mounted transformer rated 575V/34.5kV and 1.75MVA. Please see the one-line drawing (Figure 1) attached to this document.

The actual parameters (R, X and B) of the 34.5kV collector circuits are calculated based on the data provided by the customer and assumptions of typical conductor characteristics. The cable impedance characteristic table is as follows:

Cable Impedance Characteristic Table				
Drake	795 ACSR	RDC=0.0222 Ohm/1000'	XL=0.1091 Ohm/1000'	XC=0.0257 Ohm/1000'
Hawk	477 ACSR	RDC=0.0371 Ohm/1000'	XL=0.1149 Ohm/1000'	XC=0.0272 Ohm/1000'
Raven	1/0 ACSR	RDC=0.1682 Ohm/1000'	XL=0.1345 Ohm/1000'	XC=0.0315 Ohm/1000'
MV-105	1/0 Cu Shielded	RDC=0.1060 Ohm/1000'	XL=0.0500 Ohm/1000'	XC=negligible

4.2.2 Machine Dynamics Data

The GE 1.5s wind turbine generators utilize a doubly fed induction-generator with a wound rotor and slip rings. The generator synchronous speed is 1200 rpm, and a variable frequency power converter tied to the generator rotor allows the generator to operate at speeds ranging from 800 rpm to 1600 rpm. Nominal speed at 1.5MW power output is 1440 rpm and the maximum allowable non-operating rotational speed is 1680 rpm. The power converter allows the generator to produce power at a power factor of 0.9 lagging to 0.95 leading. The power factor is settable at each WTG or by the Plant SCADA system.

Shaw Power Technologies Inc. (PTI) has produced a GE 1.5s turbine model package for use on their PSS/E simulation software. This package was obtained from PTI and was used exclusively in modeling this wind farm.

The PTI model package consists of an IPLAN program that creates the dynamic stability data for the wind farm based on inputs from the user. The user is able to choose how the wind farm is dispatched (via a wind speed data set or dispatched directly), whether the turbines will be set to a specific voltage or power factor setpoint, and the protection schemes for the turbines (both frequency and voltage).

The wind farm was dispatched directly by the program to the level specified (100% rated power and 50% rated power). It was also assumed that all turbines located in the farm were in-service (50% rated power means that all 100 turbines were generating at 50% rated power). The wind farm was also set to adjust for a voltage setpoint and alternatively a power factor setpoint to investigate the behavior of the farm for the various fault situations. The default protection schemes embedded in the PTI model package were utilized for the farm.

4.2.3 Turbine Protection Schemes

The GE turbines utilize an undervoltage/overvoltage protection scheme and an underfrequency/overfrequency protection scheme. The various protection schemes are designed to protect the wind turbines in the case of system disturbances that can cause damage to the mechanical systems or power electronics on board the turbine. Generally, the protection schemes will disconnect the generator from the electric grid if the sampled frequency or voltage is outside of a specified band for a specified amount of time.

The voltage protection scheme is outlined in Table 1 below:

Voltage	Time Limit
1.3000pu +	1.2 cycles (0.02s)
1.1500pu -- 1.299pu	6 cycles (0.1s)
1.1499pu – 1.1000pu	12 cycles (0.2s)
1.0999pu – 0.9001pu	Continuous Operation
0.9000pu -- 0.8001pu	36000 cycles (10min) *Assumed Continuous Operation
0.8000pu – 0.7001pu	600 cycles (10.0s)
0.7000pu – 0.3001pu	60 cycles (1.0s)
0.3000pu – 0.0000pu	1.2 cycles (0.02s)

Table 1: GE 1.5s Turbine Voltage Protection

The frequency protection scheme is outlined in Table 2 below:

Frequency	Time Limit
61.7000Hz +	1.2 cycles (0.02s)
61.6999Hz -- 61.500Hz	1800 cycles (30.0s)
61.4999Hz -- 58.5001Hz	Continuous Operation
58.5000Hz – 57.9001Hz	450 cycles (7.5s)
57.9000Hz – 57.4001Hz	45 cycles (0.75s)
56.9000Hz – 56.5001Hz	7.2 cycles (0.12s)
56.5000Hz – 0.0000Hz	1.2 cycles (0.02s)

Table 2: GE 1.5s Turbine Frequency Protection

4.2.4 Stability Results

The wind farm and the surrounding transmission system appear to remain stable for all faults applied and for all scenarios analyzed. The wind farm does not trip due to the faults. Voltage and frequency appear to recover nicely for all cases and scenarios. Speeds of machines in the SPS area and the wind farm appear to remain within limits. All cases and scenarios are tabulated below:

Fault Case/Scenario	81MW only (Power Factor Control)	81MW only (Voltage Control)	40.5MW only (Voltage Control)
FLT_1_3PH	---	---	---
FLT_2_1PH	---	---	---
FLT_3_3PH	---	---	---
FLT_4_1PH	---	---	---
FLT_5_3PH	---	---	---
FLT_6_1PH	---	---	---
FLT_7_3PH	---	---	---
FLT_8_3PH	---	---	---
FLT_9_1PH	---	---	---
FLT_10_3PH	---	---	---
FLT_11_1PH	---	---	---
FLT_12_3PH	---	---	---
FLT_13_1PH	---	---	---
FLT_14_3PH	---	---	---
FLT_15_1PH	---	---	---

O = wind farm tripped due to high voltage
X = wind farm tripped due to low voltage
--- = wind farm did not trip
@ = some of the farm tripped

Originally, all fault simulations were run out to a period of 10.0 seconds to allow all transients to subside. However, upon further examination of wind turbine generator speed and rotor angles, it was found that these properties did not stop moving around until nearly 15.0 seconds into the simulation. All scenarios/faults were re-run to a period of 20.0 seconds to verify that the wind turbines achieved stable operation. This slow reaction results from the relatively slow speeds at which the turbines operate and the relatively “soft” shaft between the propeller and machine.

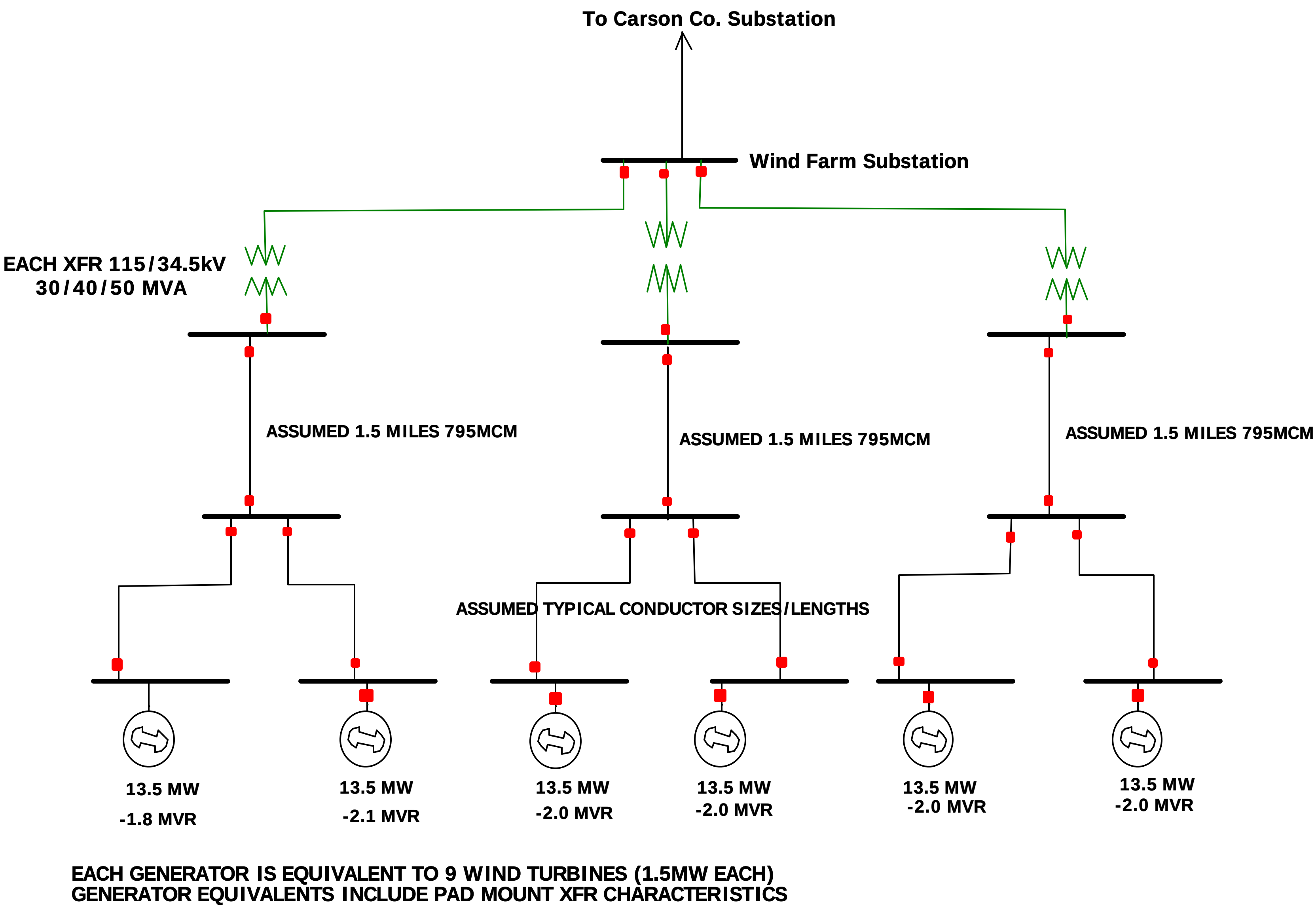
Other wind farms modeled in the case (GEN-2002-006, -008, and –009), which have higher queue priority than this request, did experience tripping for faults 10 and 12. These faults were considered close-in faults to the other wind farms and thus it was expected that those farms would possibly trip due to the fault. The remaining system and the GEN-2003-009 wind farm remained stable and online regardless of the tripping of the other higher queued requests.

5.0 Conclusion

No stability concerns presently exist for the wind farm as proposed and studied. However, changes to the farm design or equipment configuration would require a re-visit of these study results. At this time, there are no recommendations for further facilities that would be required for interconnection.

The minimum cost of interconnecting the Customer project is $3.1 million. However, as stated earlier, some previously queued projects were assumed to not be in service in this System Impact Study. If any of those projects are constructed, then this System Impact Study may have to be revisited to determine the impacts of this customer's project on other SPS transmission facilities. It should be noted that the models used for simulation do not contain all SPP transmission service. The models do contain all the firm transmission service included by the transmission owners in their model updates for SPP's planning models. These costs also do not take into account any breaker duty ratings or settings. The short circuit analysis will be performed as part of the Facility Study performed by SPS if the customer elects to have the study performed.

The costs do not include any costs associated with the deliverability of the energy to final customers. These costs are determined by separate studies if the Customer requests transmission service through Southwest Power Pool's OASIS.



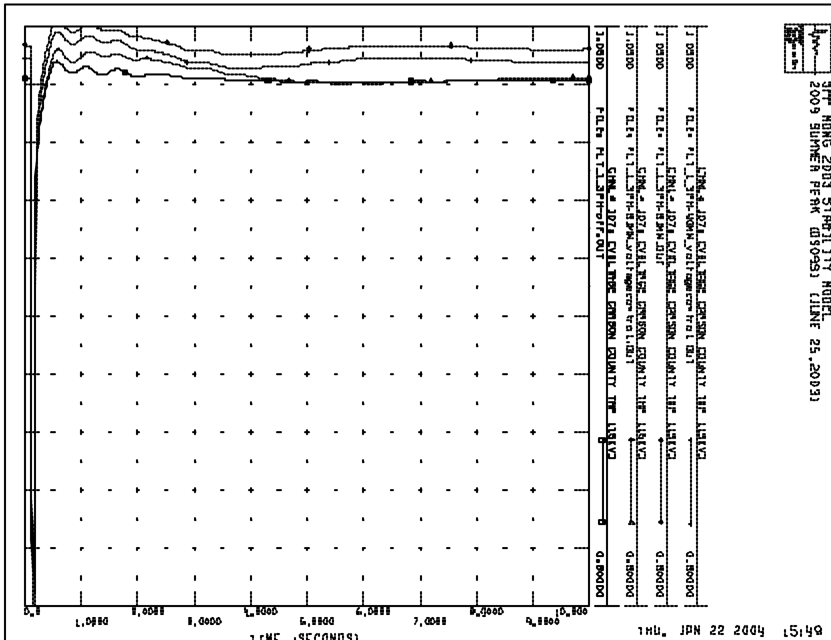
EQUIVALENT WIND FARM LAYOUT

Figure 1

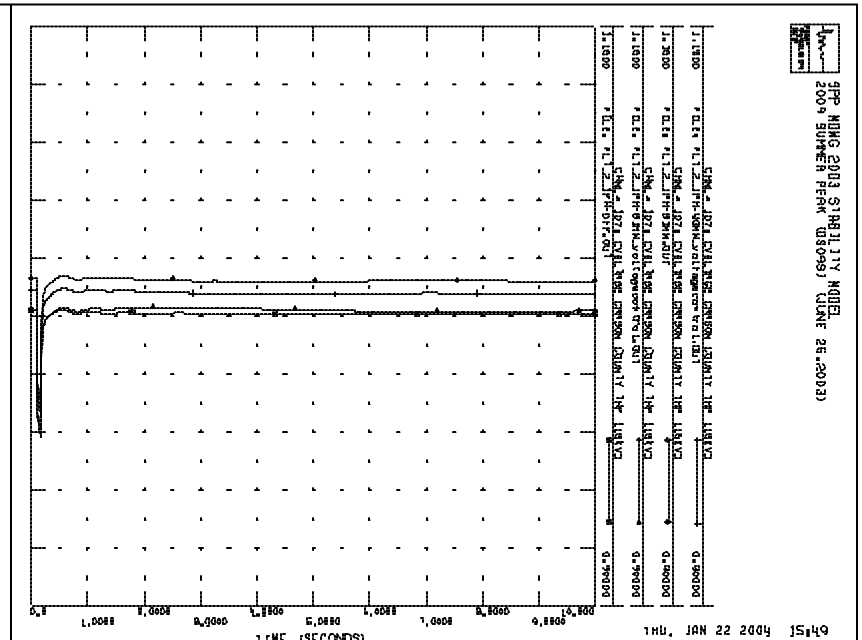
Appendix A

Plots of Fault Simulations

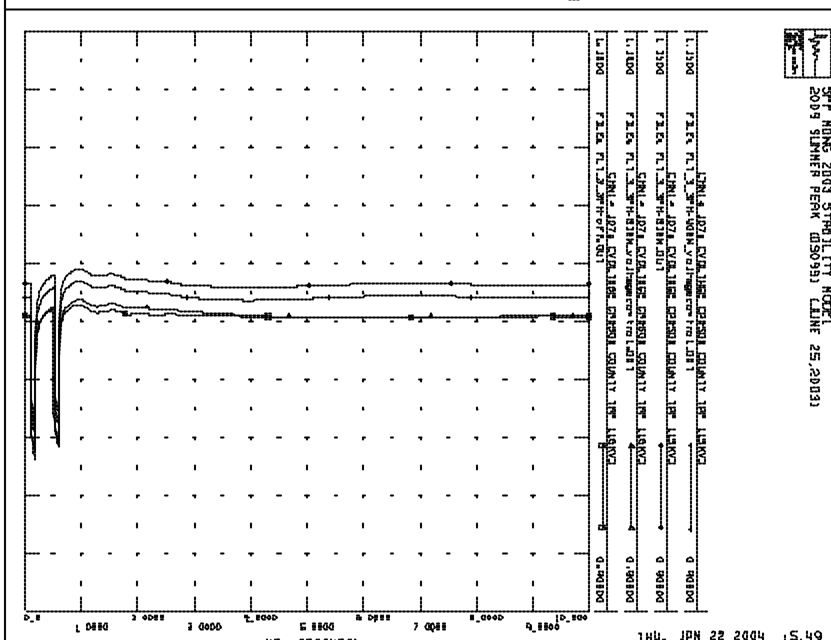
(Comparison of Carson Co. Voltages for all scenarios)



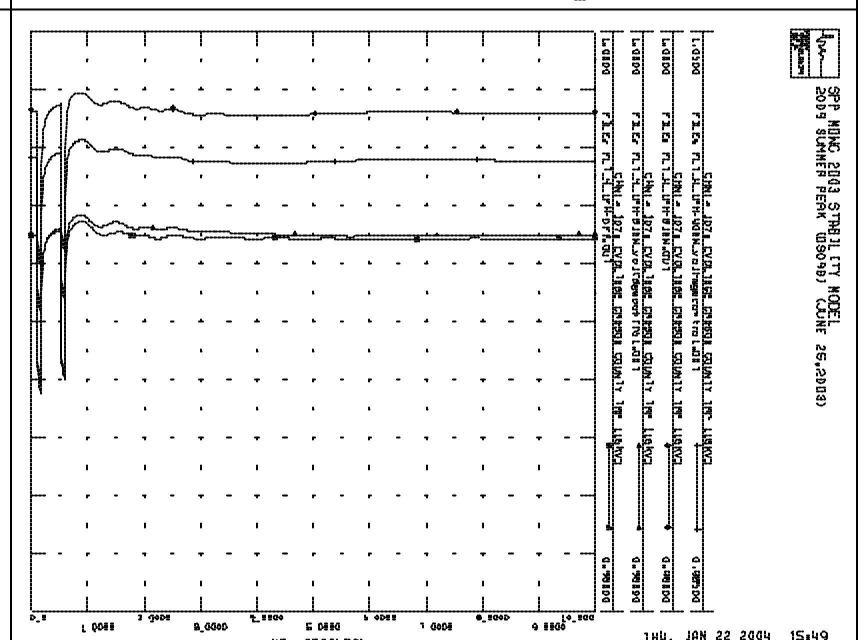
FLT_1 CARSON CO. VOLTAGE



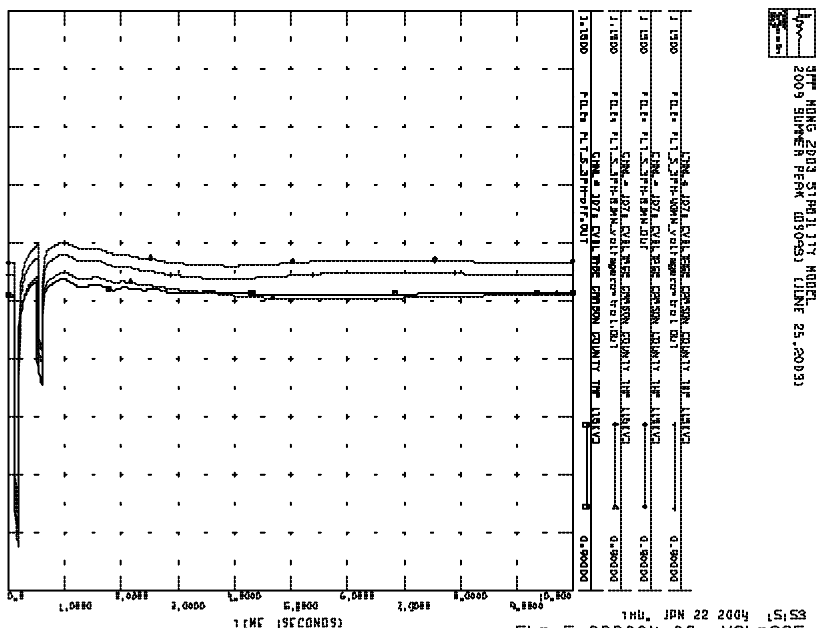
FLT_2 CARSON CO. VOLTAGE



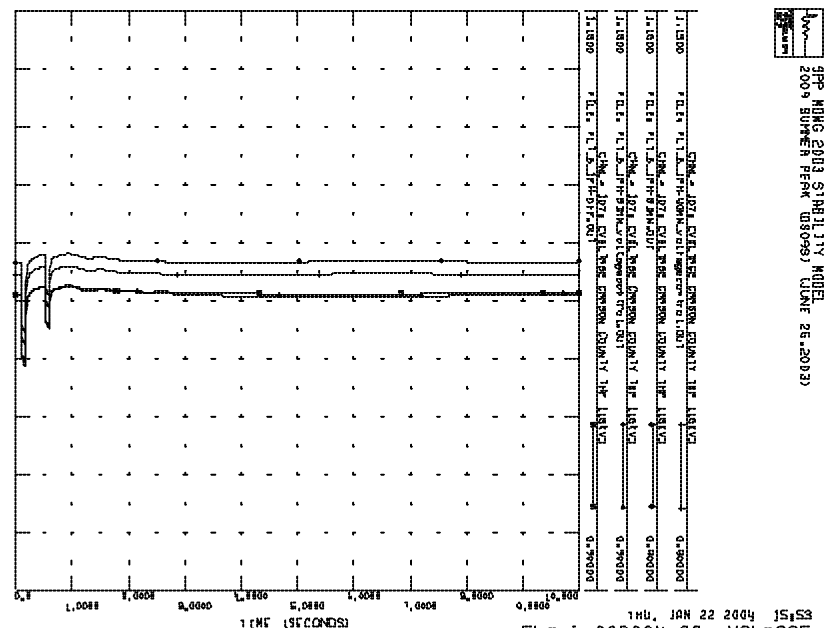
FLT_3 CARSON CO. VOLTAGE



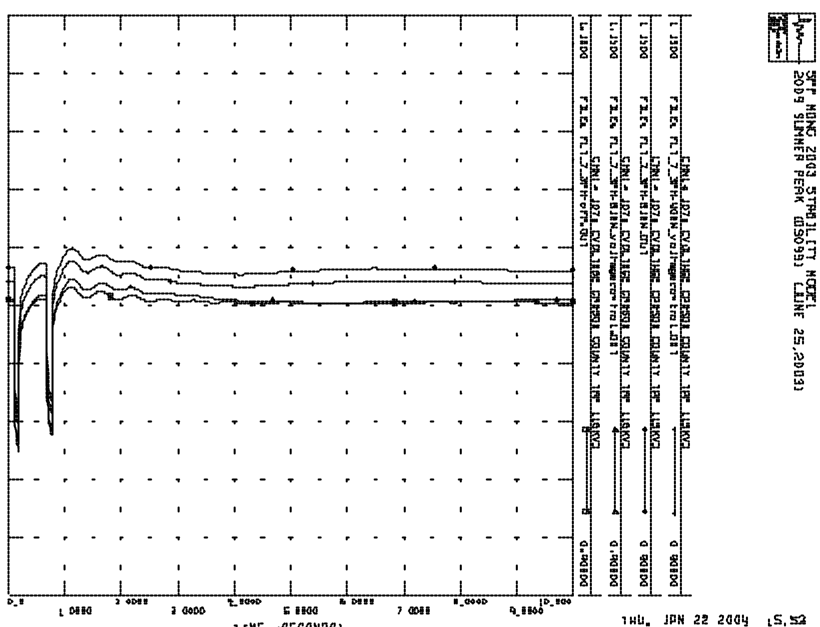
FLT_4 CARSON CO. VOLTAGE



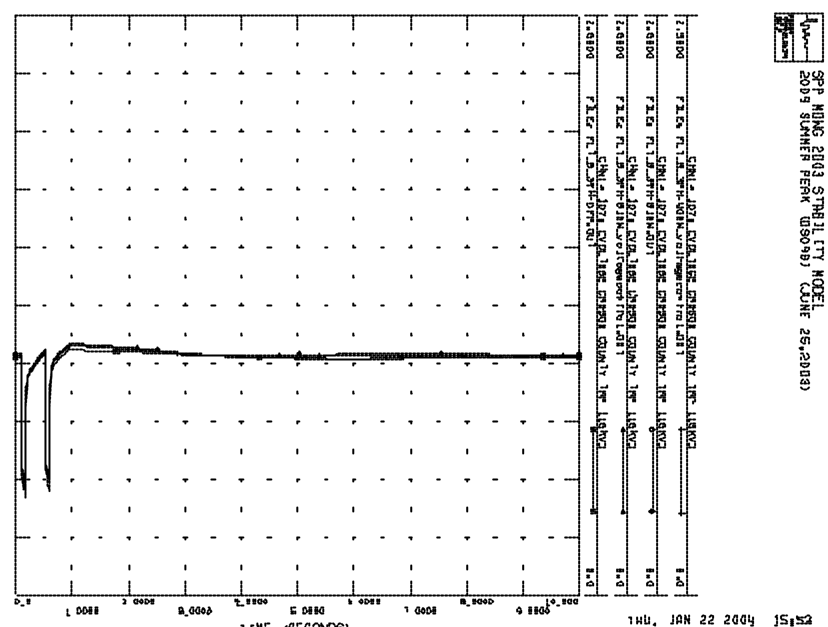
FLT_5 CARSON CO. VOLTAGE



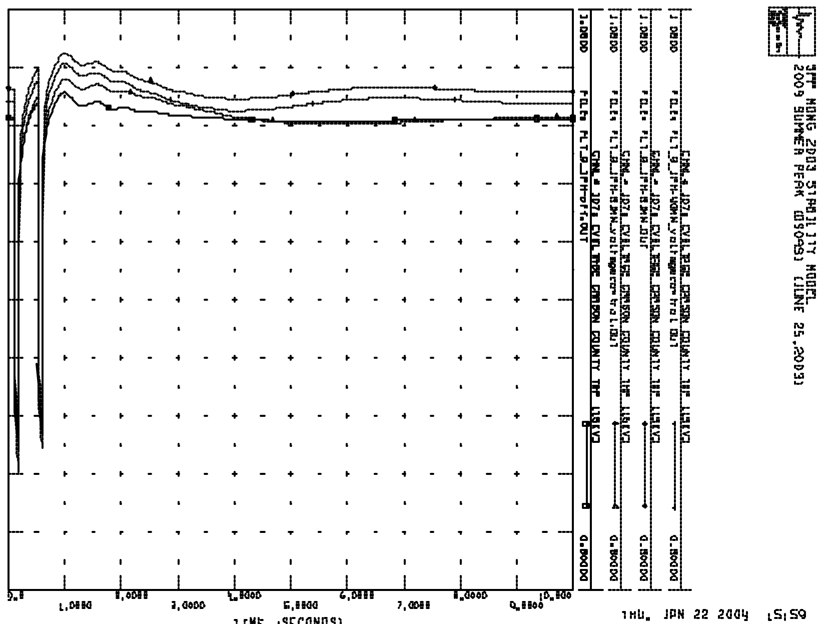
FLT_6 CARSON CO. VOLTAGE



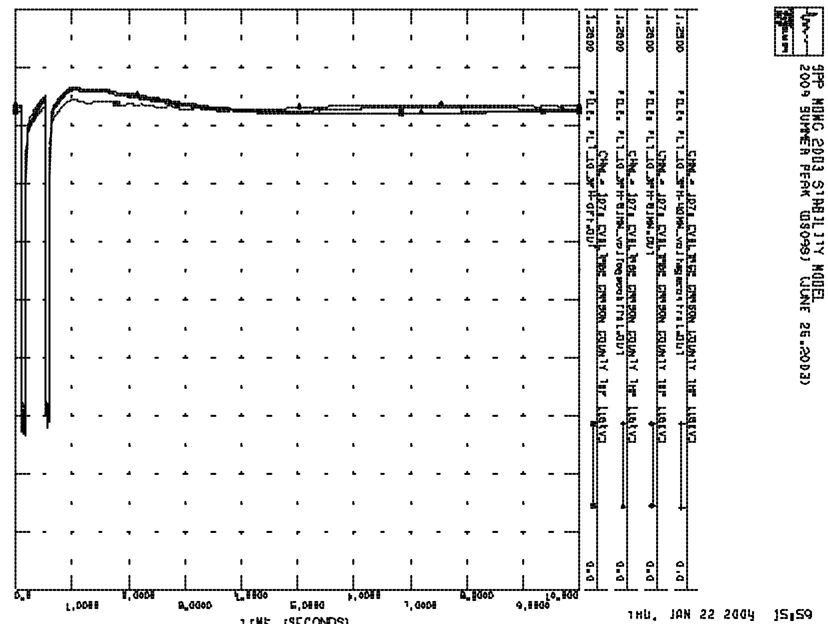
FLT_7 CARSON CO. VOLTAGE



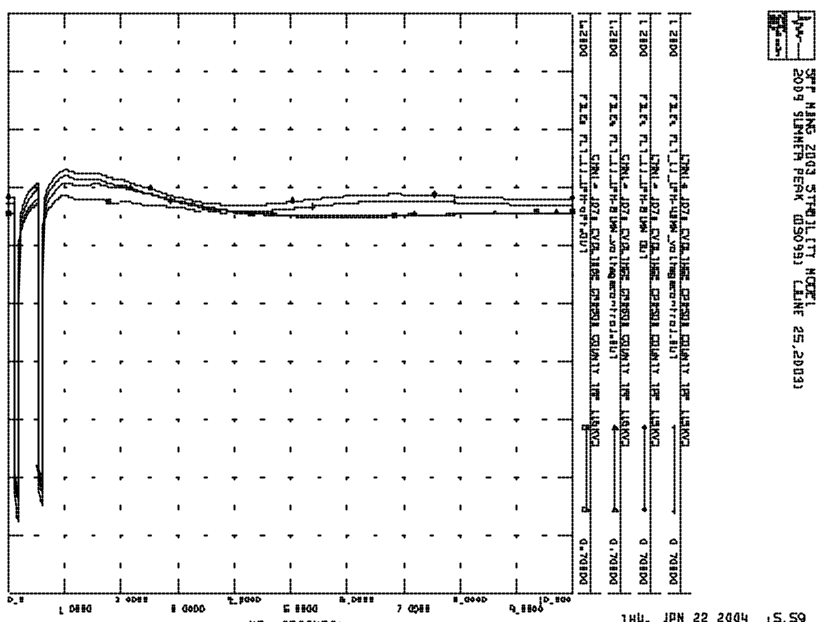
FLT_8 CARSON CO. VOLTAGE



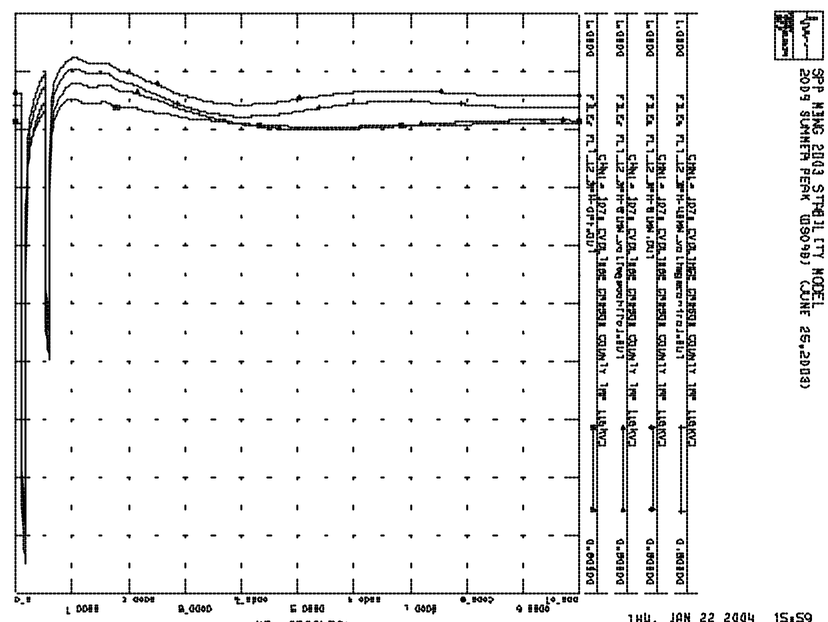
FLT_9 CARSON CO. VOLTAGE



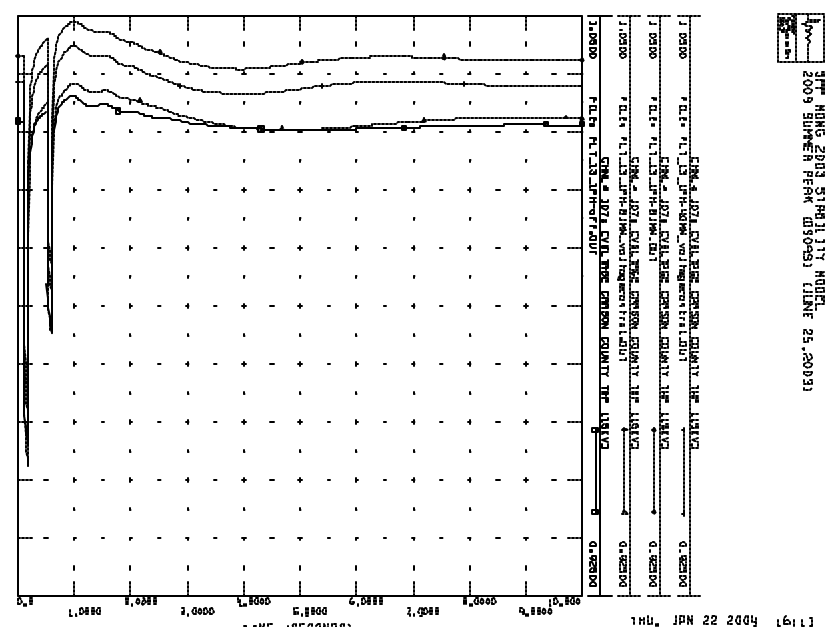
FLT_10 CARSON CO. VOLTAGE



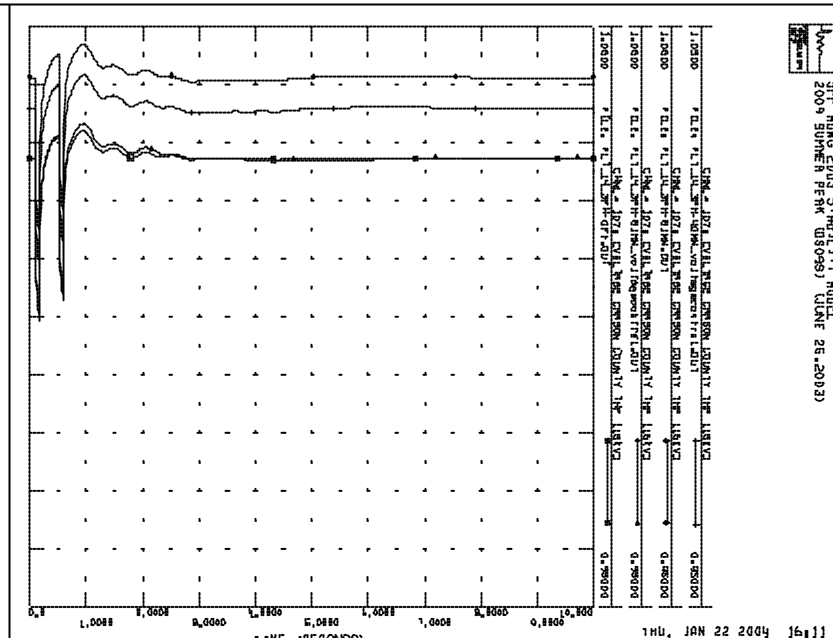
FLT_11 CARSON CO. VOLTAGE



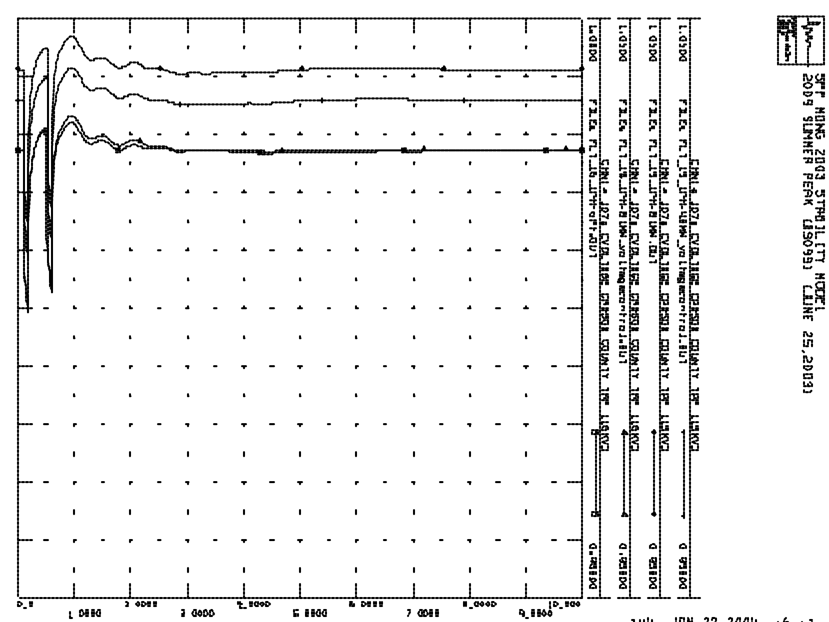
FLT_12 CARSON CO. VOLTAGE



FLT_13 CARSON CO. VOLTAGE



FLT_14 CARSON CO. VOLTAGE



FLT_15 CARSON CO. VOLTAGE

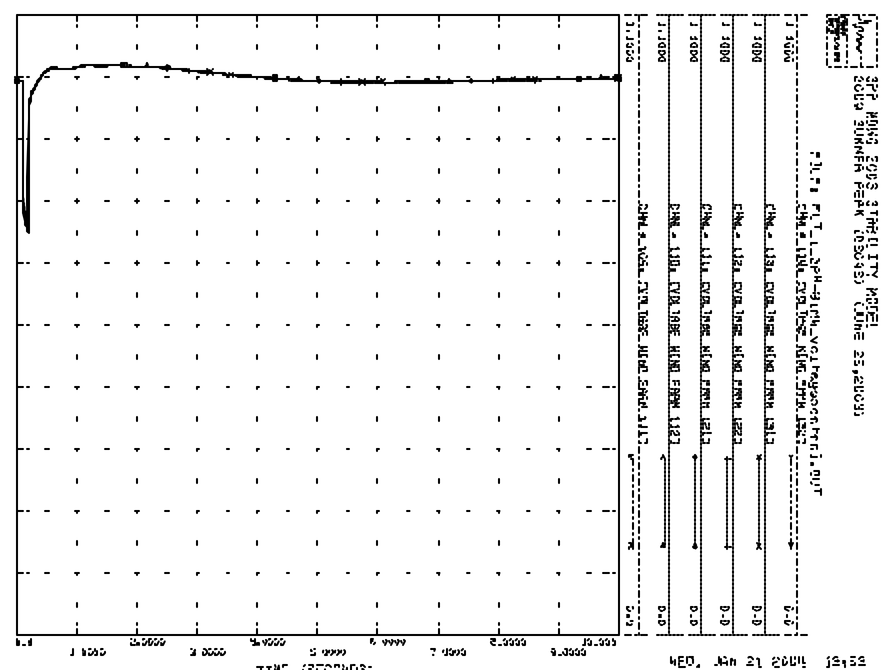
Appendix B

Plots of Fault Simulations

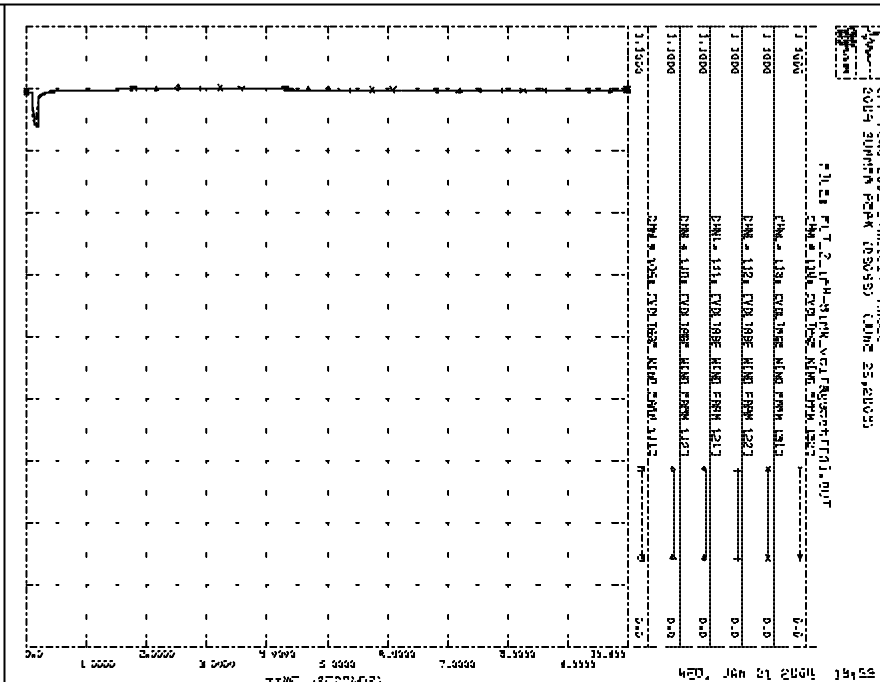
Section 1

Plots of Wind Farm generators voltage response during faults

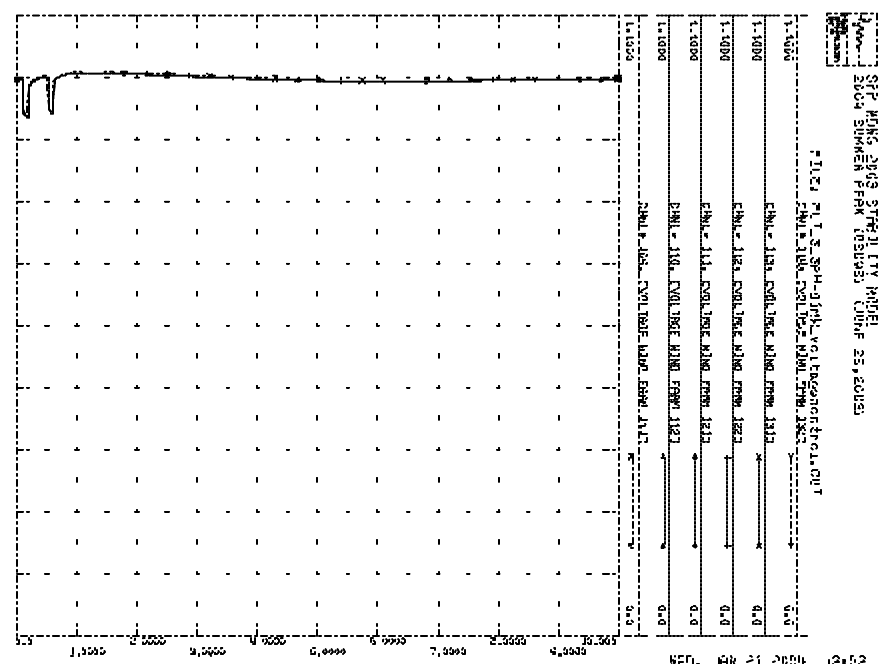
Scenario: Wind Farm at 81MW output and Voltage Control enabled



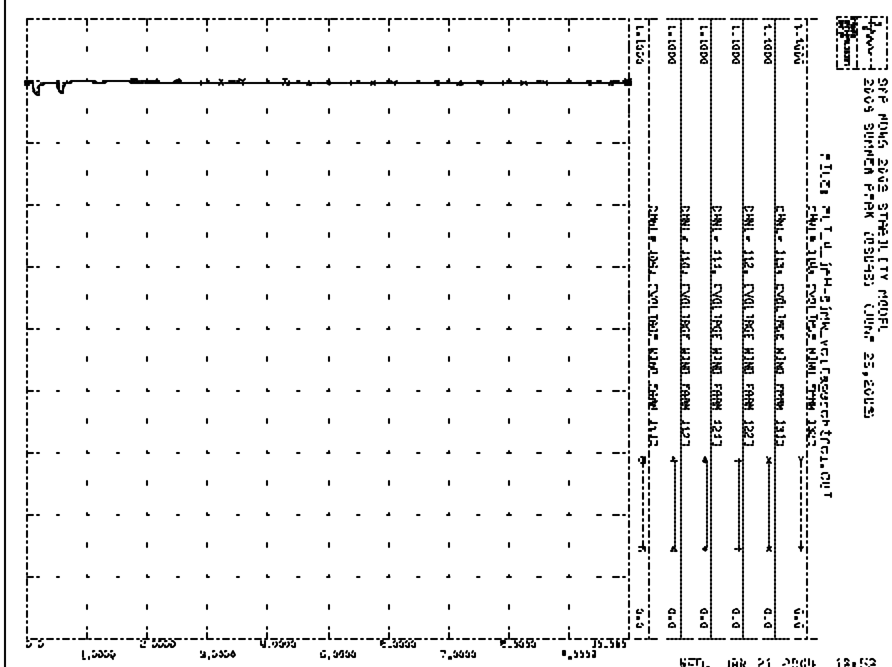
FLT_1 WIND FARM VOLTAGES



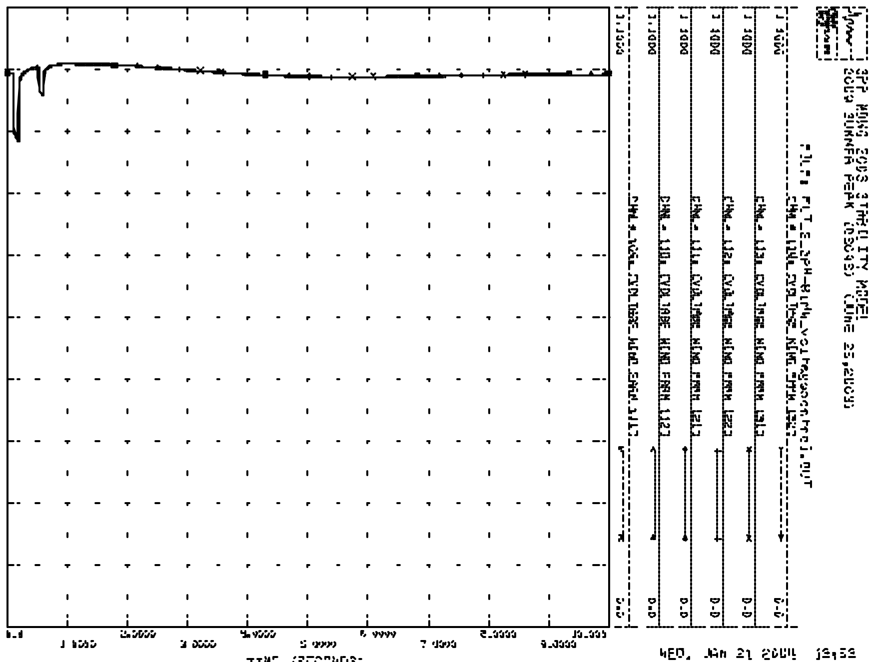
FLT_2 WIND FARM VOLTAGES



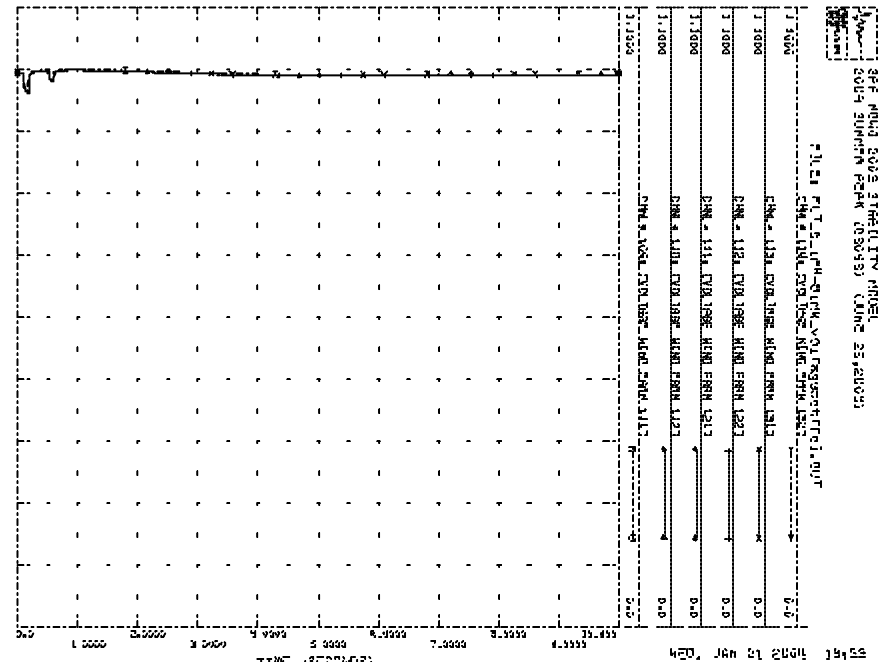
FLT_3 WIND FARM VOLTAGES



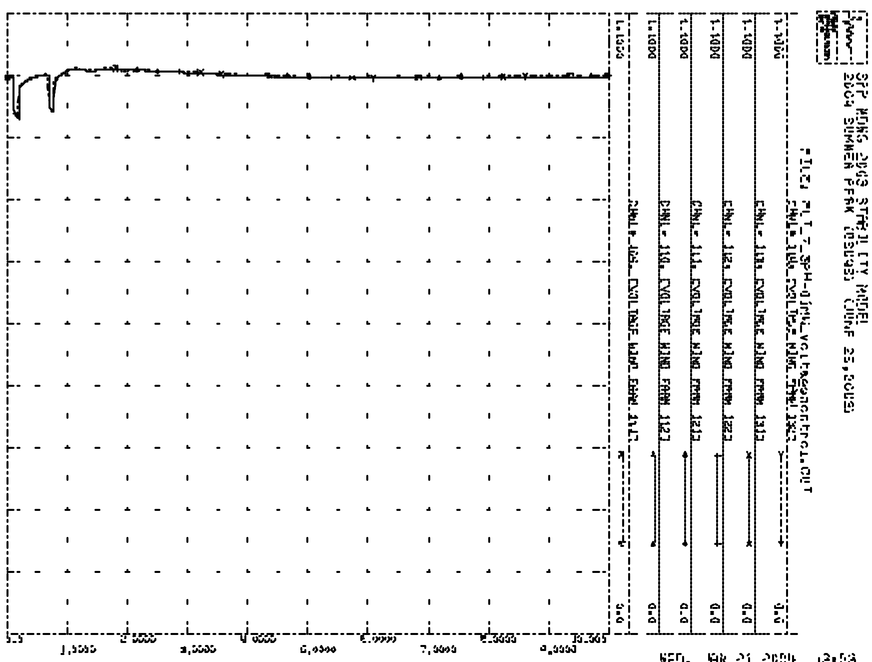
FLT_4 WIND FARM VOLTAGES



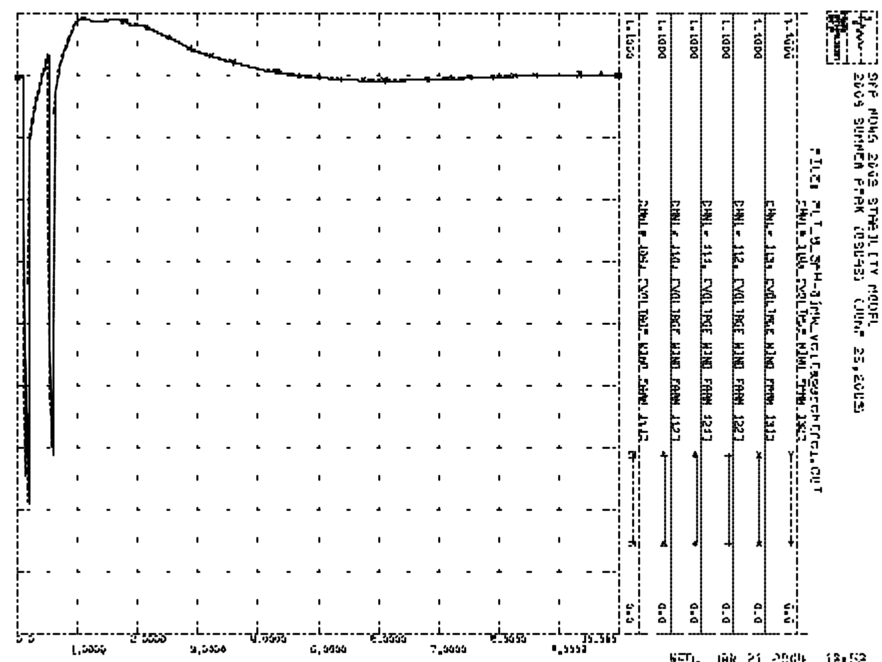
FLT_5 WIND FARM VOLTAGES



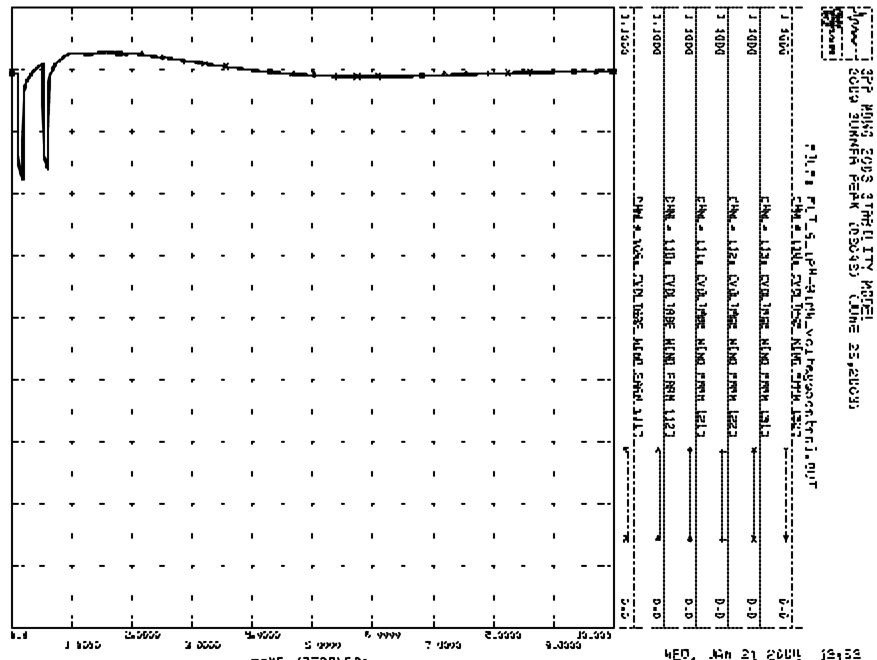
FLT_6 WIND FARM VOLTAGES



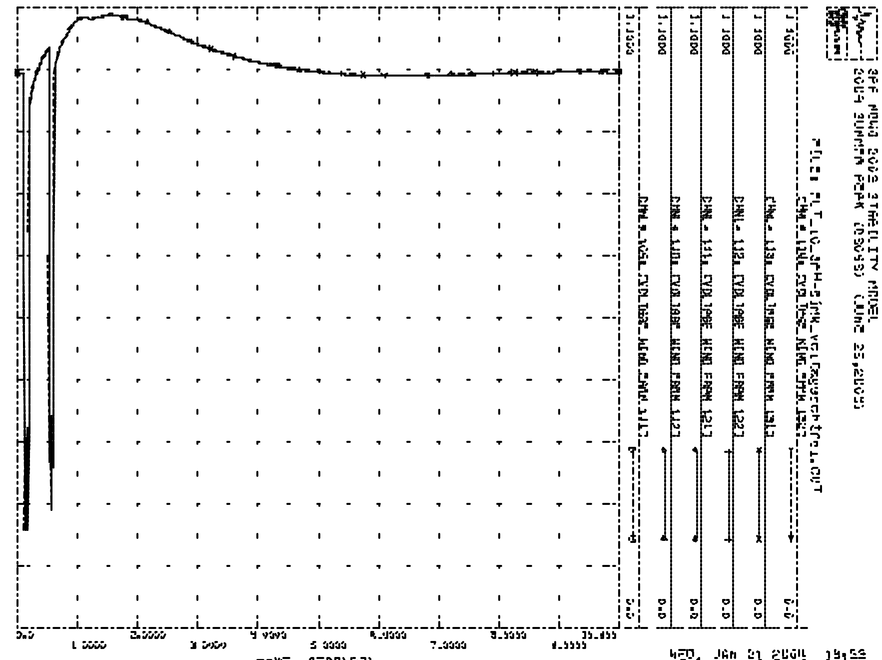
FLT_7 WIND FARM VOLTAGES



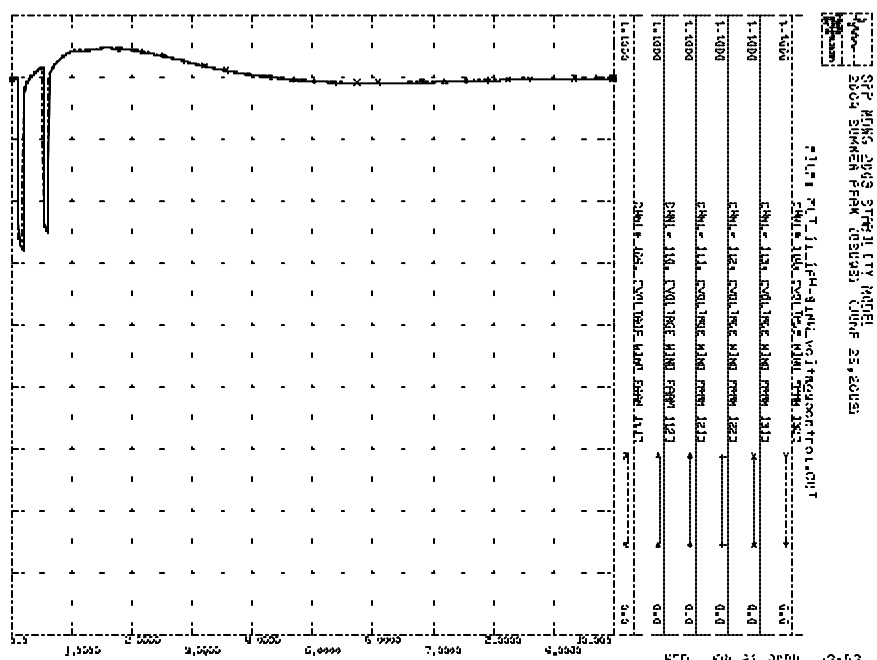
FLT_8 WIND FARM VOLTAGES



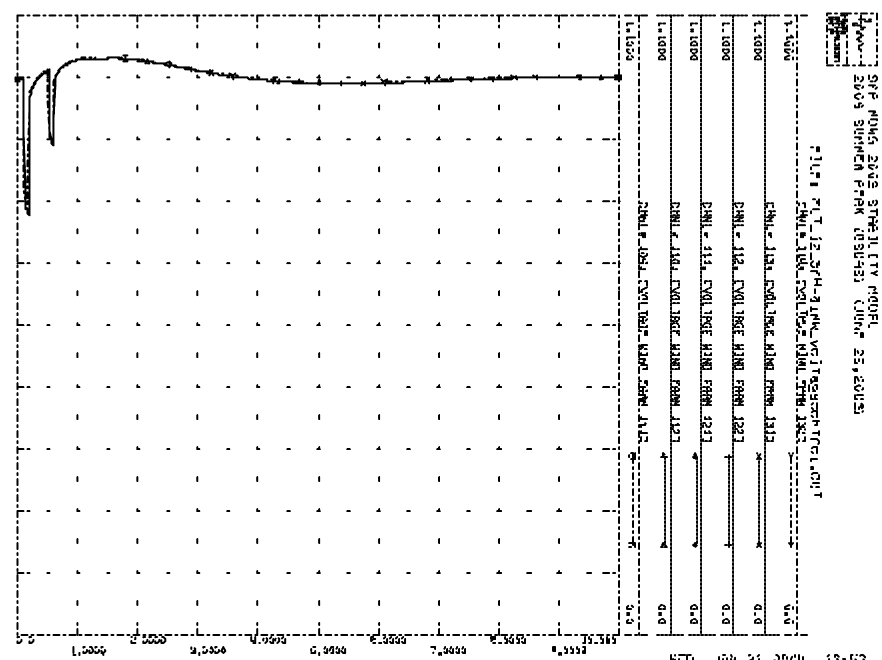
FLT_9 WIND FARM VOLTAGES



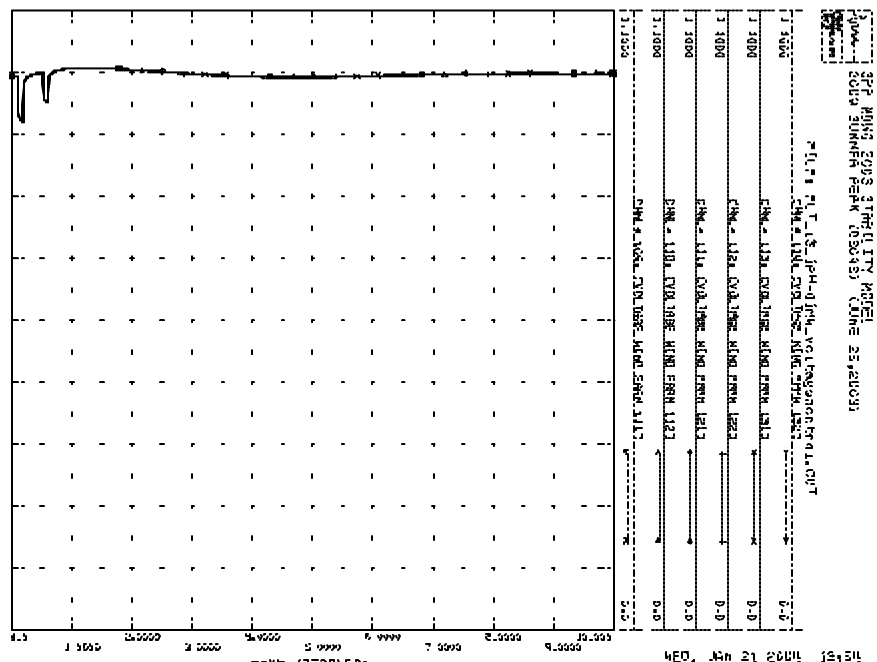
FLT_10 WIND FARM VOLTAGES



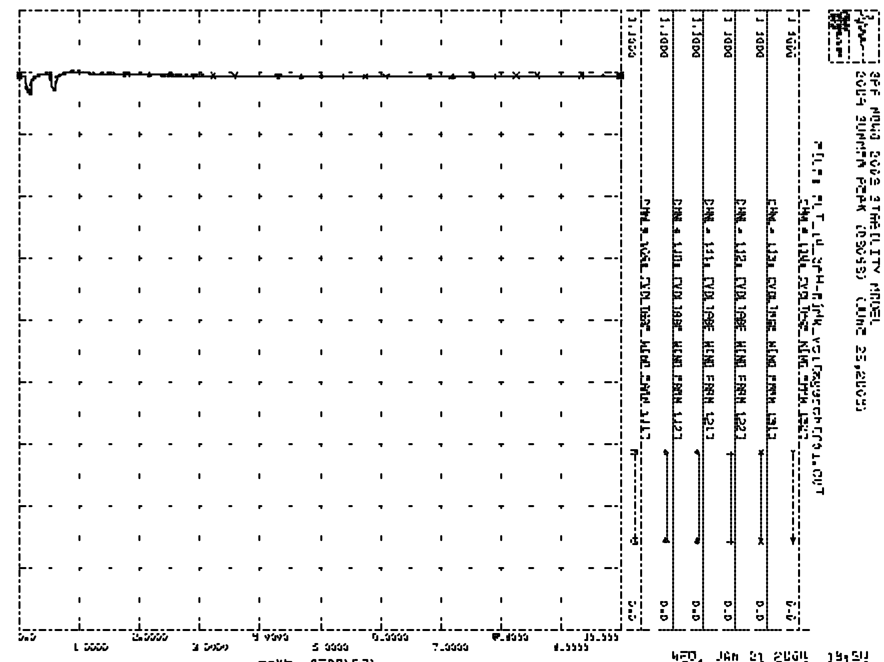
FLT_11 WIND FARM VOLTAGES



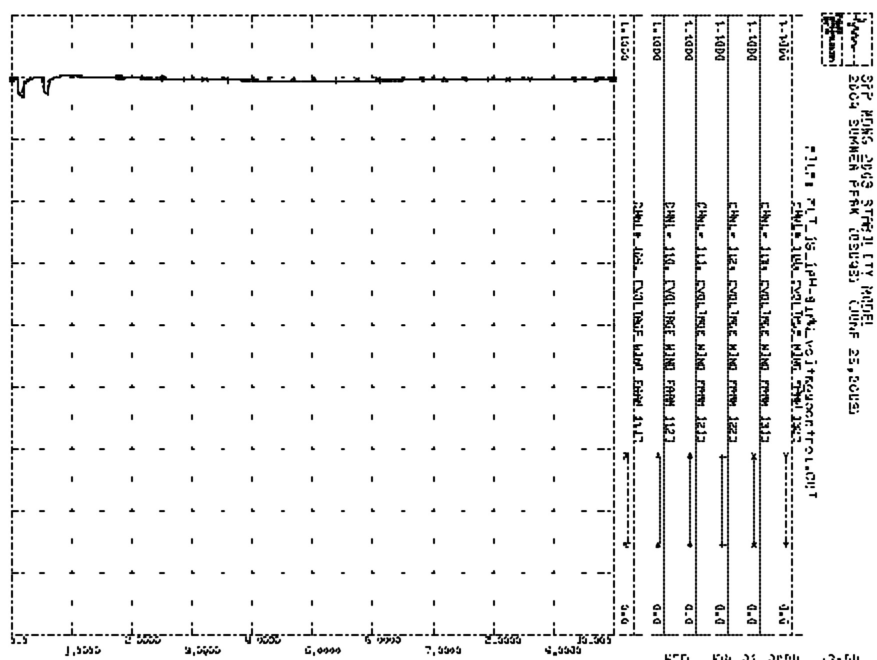
FLT_12 WIND FARM VOLTAGES



FLT_13 WIND FARM VOLTAGES



FLT_14 WIND FARM VOLTAGES



FLT_15 WIND FARM VOLTAGES

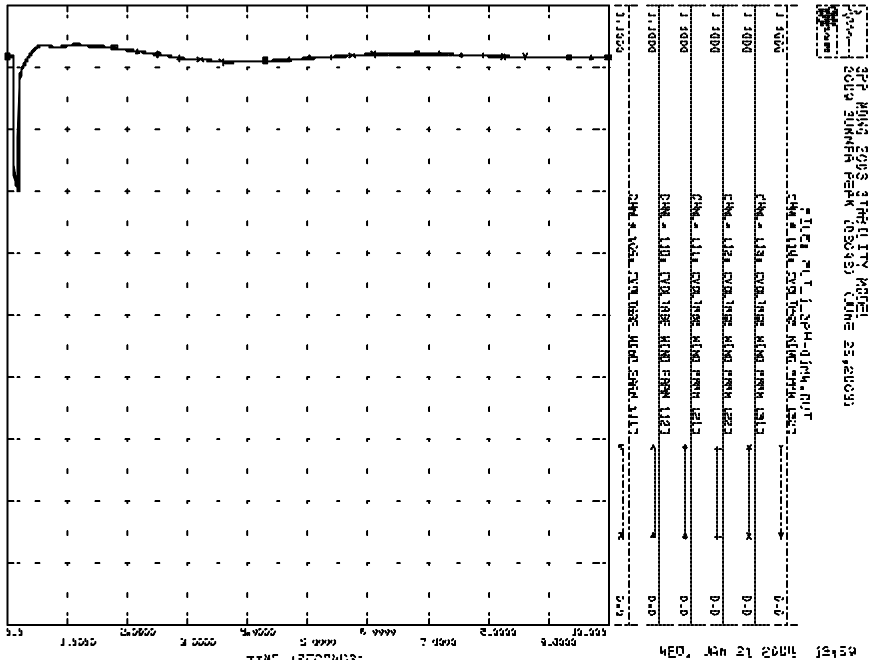
Appendix B

Plots of Fault Simulations

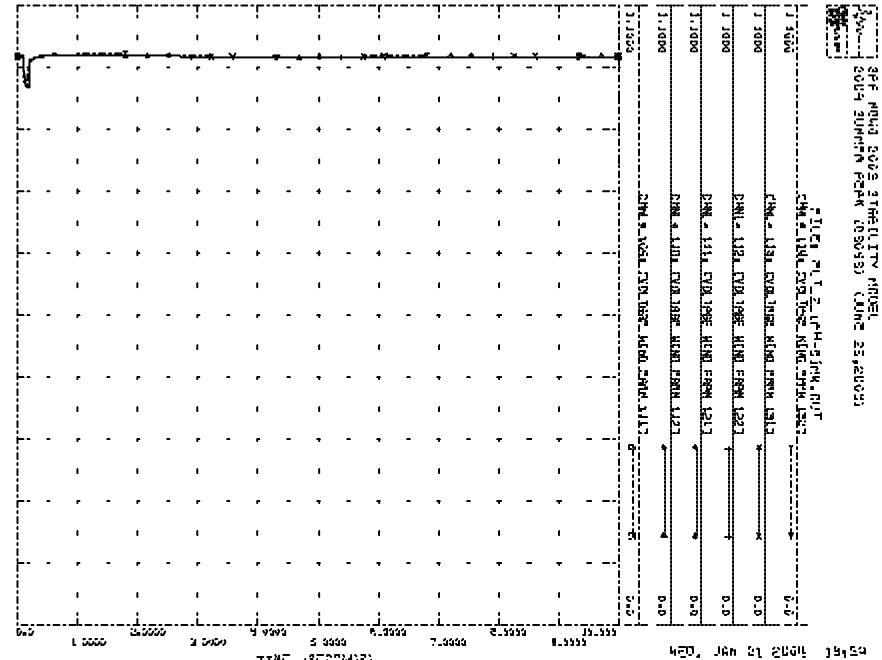
Section 2

Plots of Wind Farm generators voltage response during faults

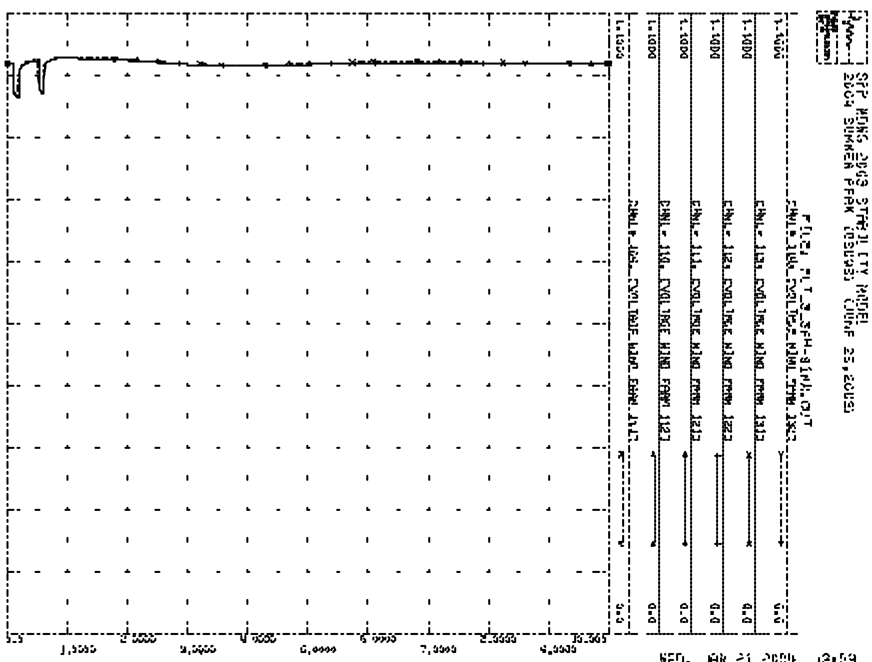
Scenario: Wind Farm at 81MW output and Power Factor Control enabled



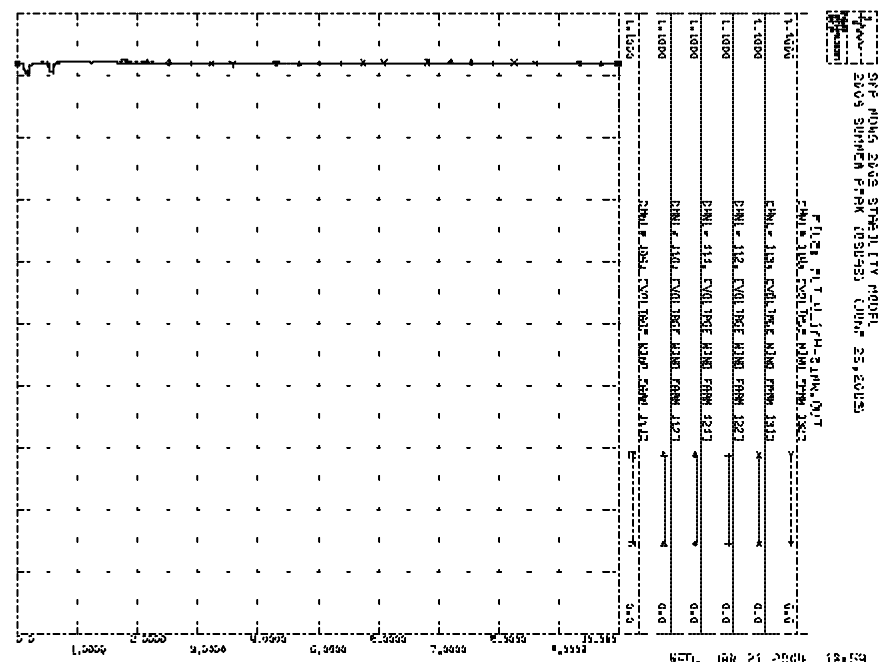
FLT_1 WIND FARM VOLTAGES



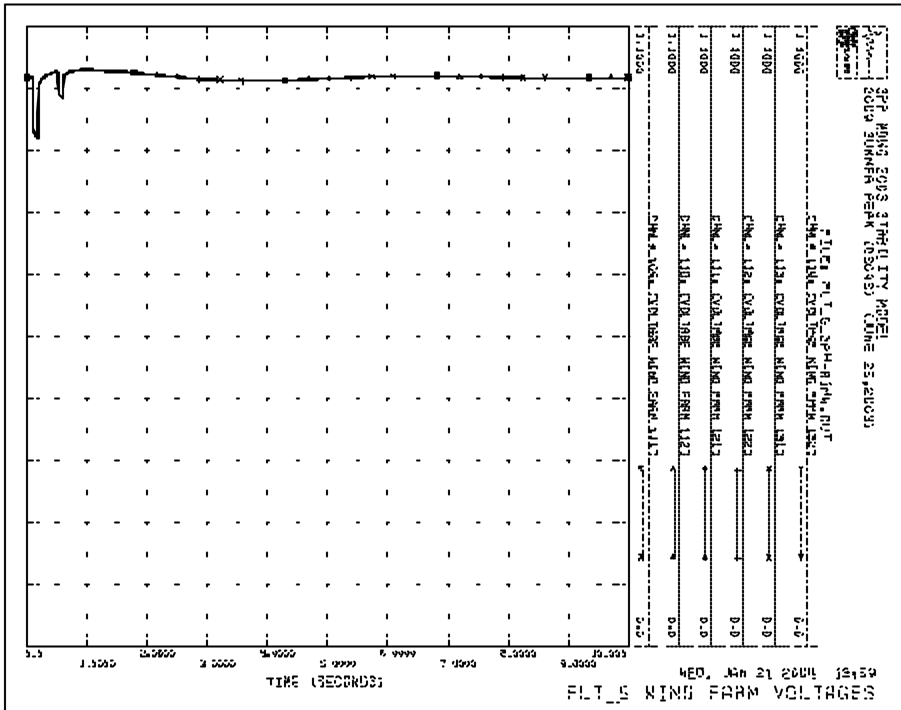
FLT_2 WIND FARM VOLTAGES



FLT_3 WIND FARM VOLTAGES



FLT_4 WIND FARM VOLTAGES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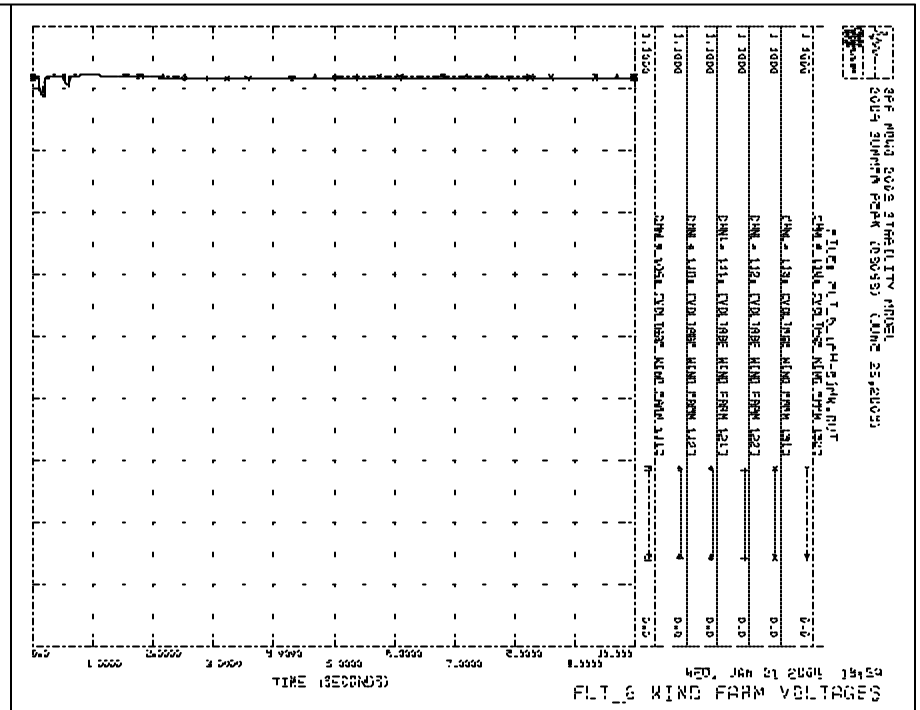
FLT_5 WIND FARM VOLTAGES


TIME (SECONDS)
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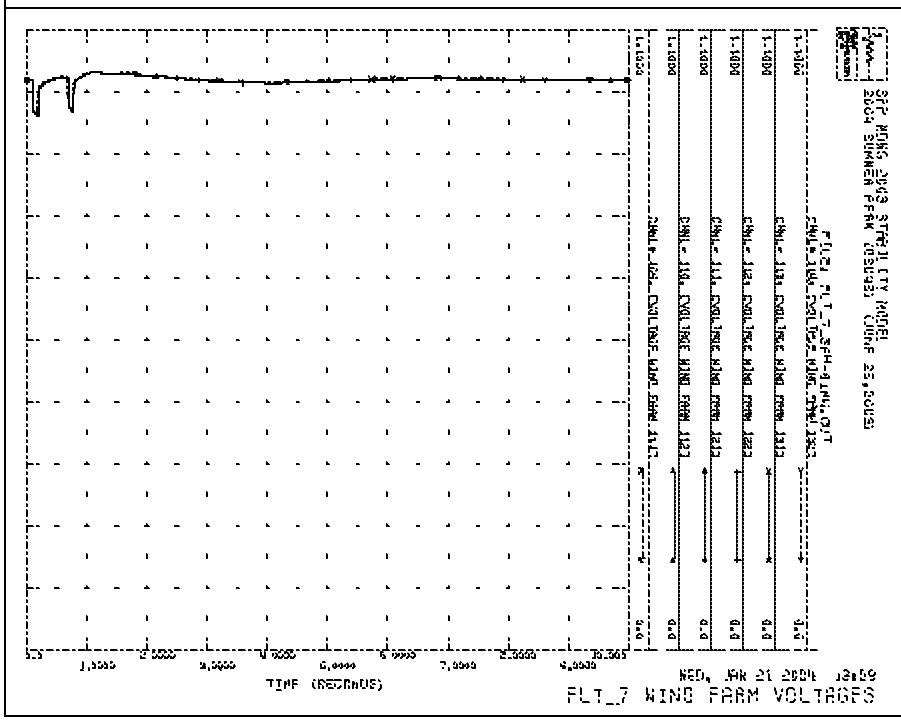
FLT_6 WIND FARM VOLTAGES


TIME (SECONDS)
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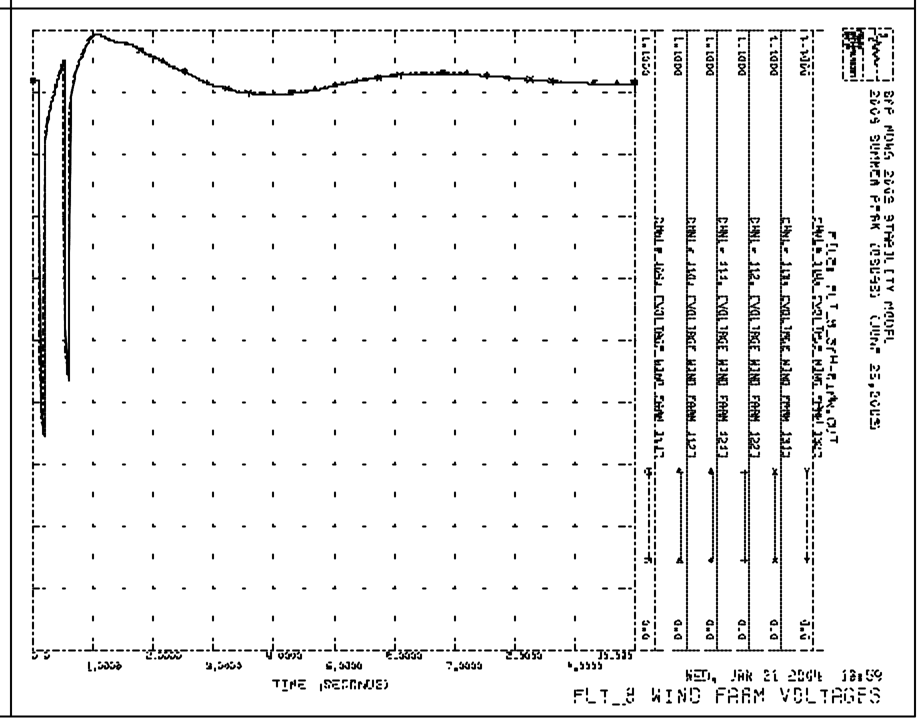
FLT_7 WIND FARM VOLTAGES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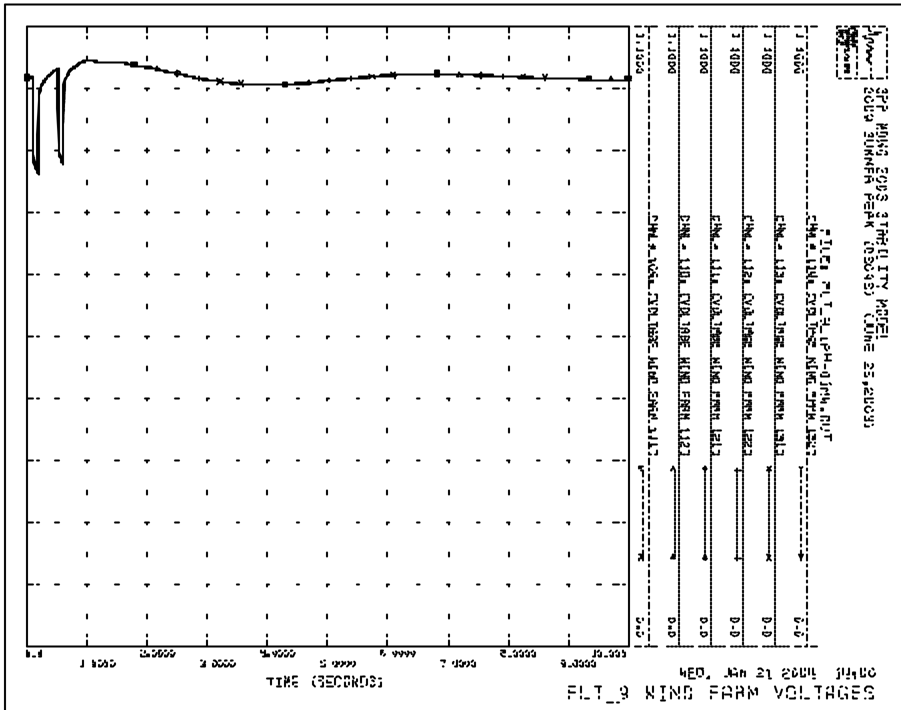
FLT_8 WIND FARM VOLTAGES


TIME (SECONDS)
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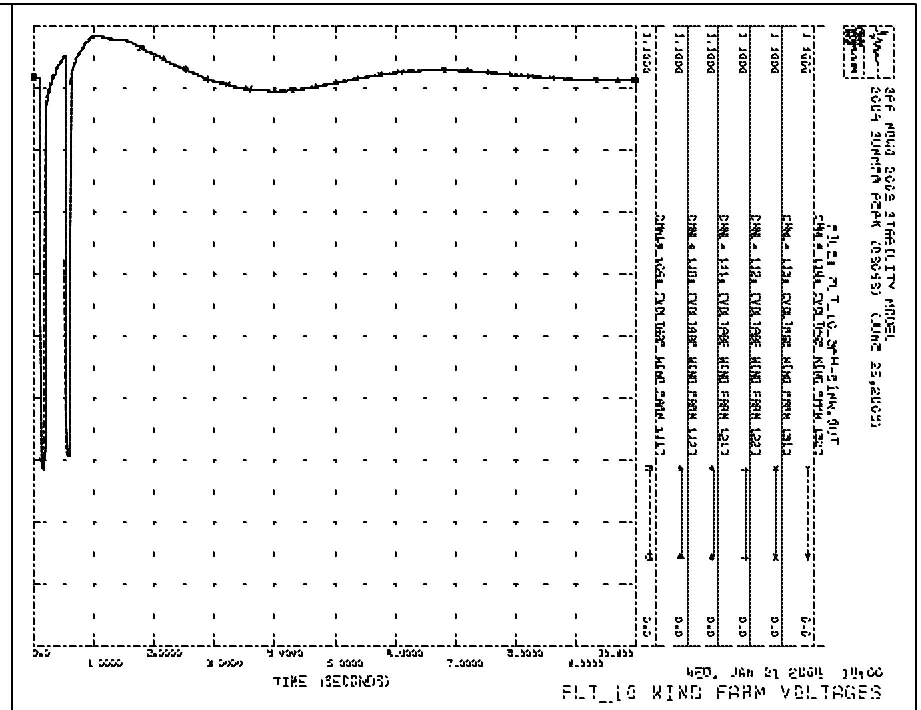
FLT_9 WIND FARM VOLTAGES


TIME (SECONDS)
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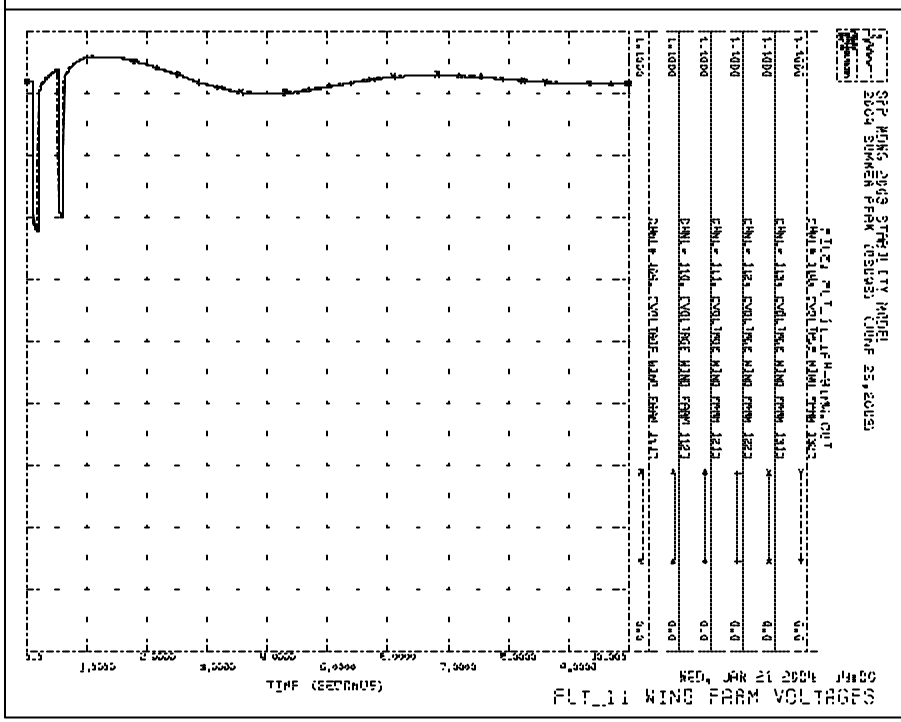
FLT_10 WIND FARM VOLTAGES


TIME (SECONDS)
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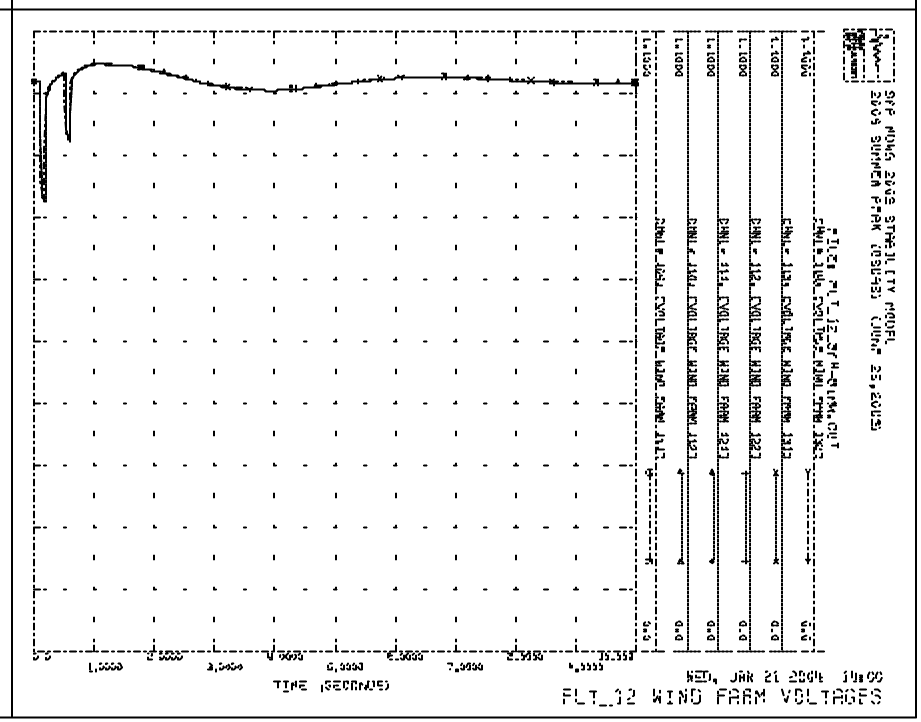
FLT_11 WIND FARM VOLTAGES


TIME (SECONDS)
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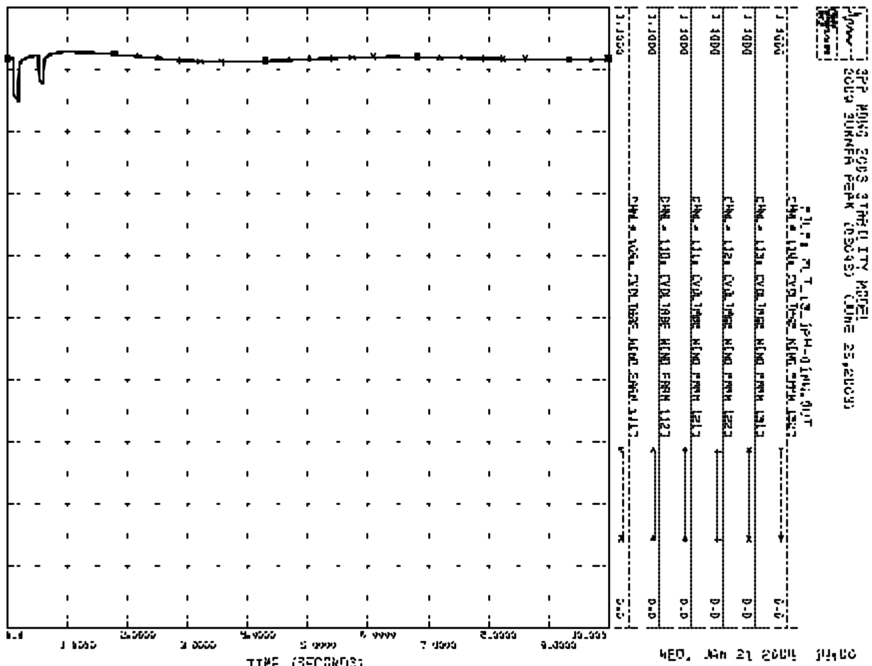
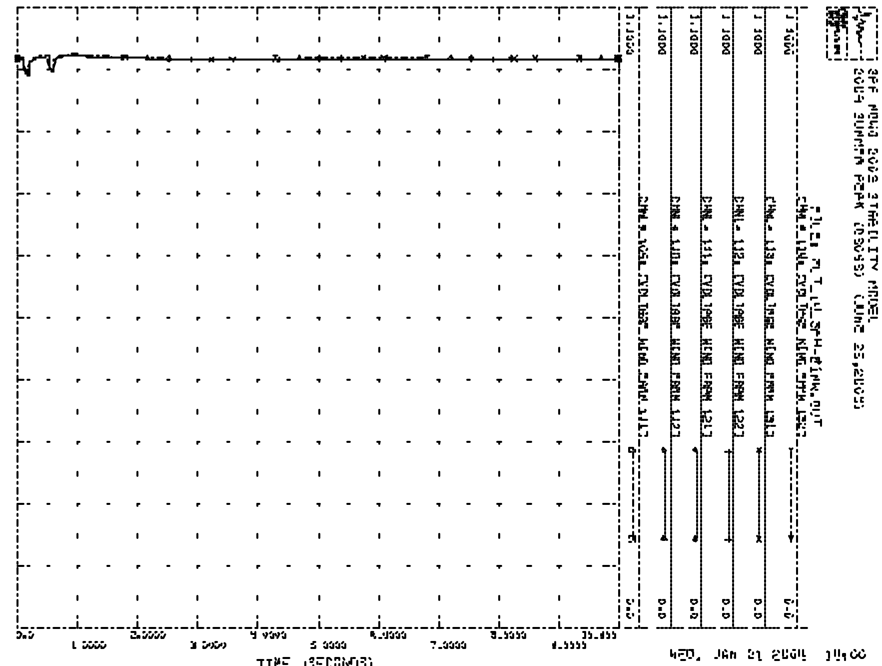
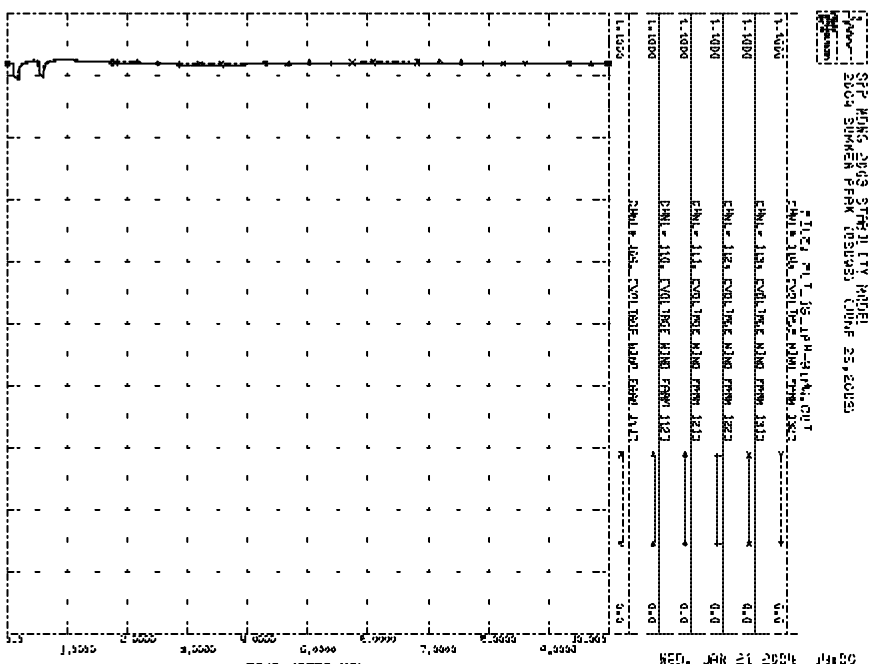
FLT_12 WIND FARM VOLTAGES



FLT_13 WIND FARM VOLTAGES



FLT_14 WIND FARM VOLTAGES



FLT_15 WIND FARM VOLTAGES

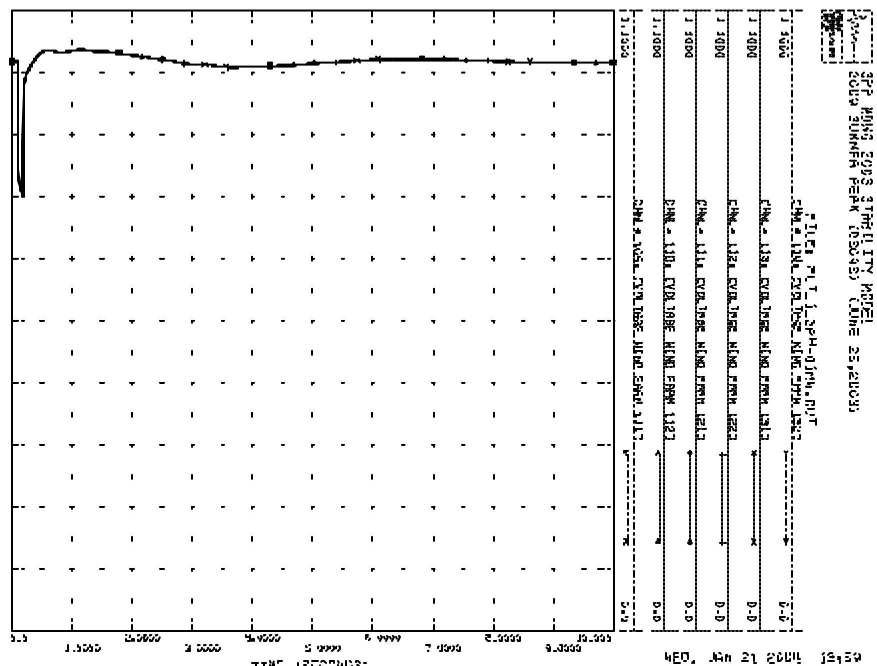
Appendix B

Plots of Fault Simulations

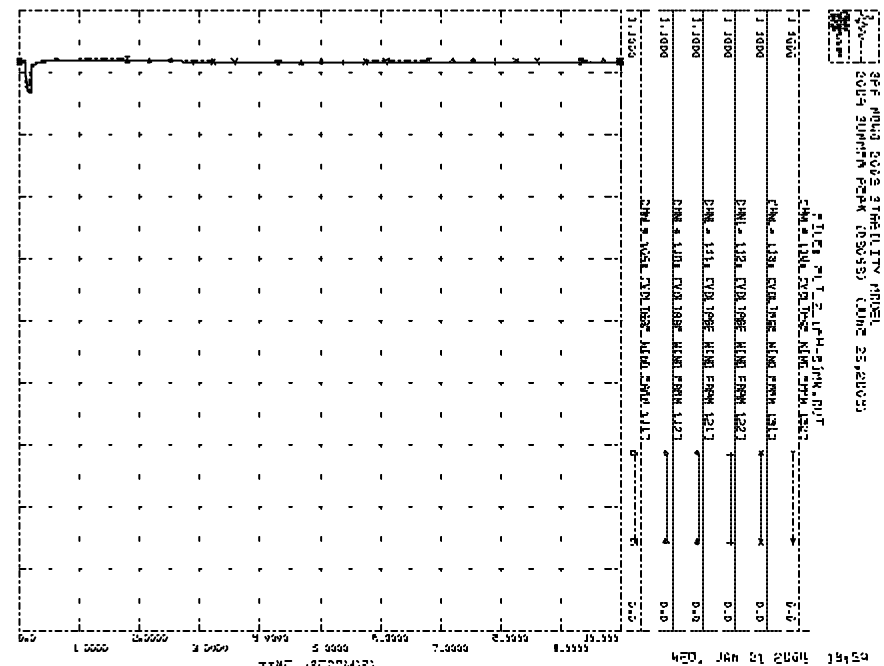
Section 3

Plots of Wind Farm generators voltage response during faults

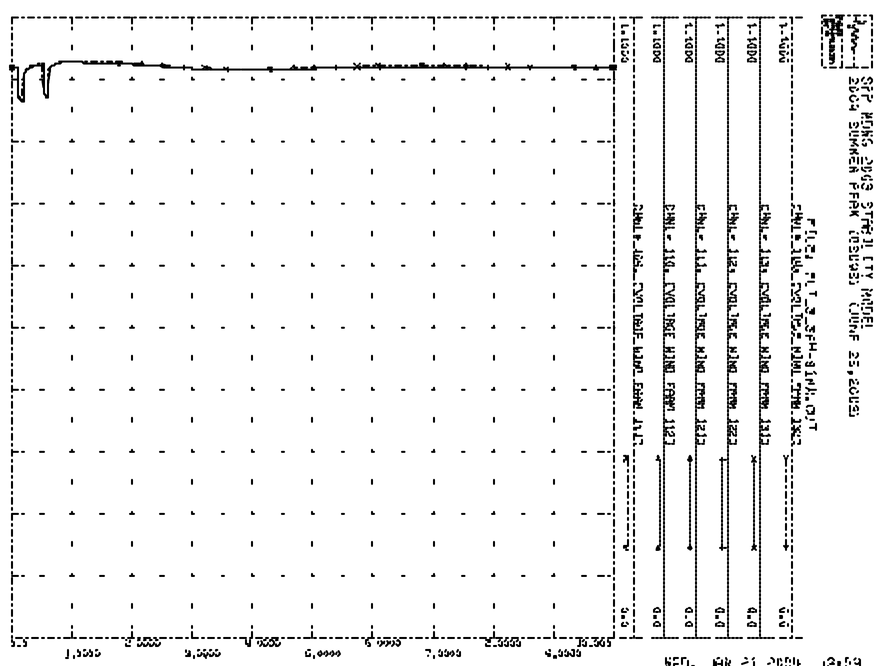
Scenario: Wind Farm at 40.5MW output and Voltage Control enabled



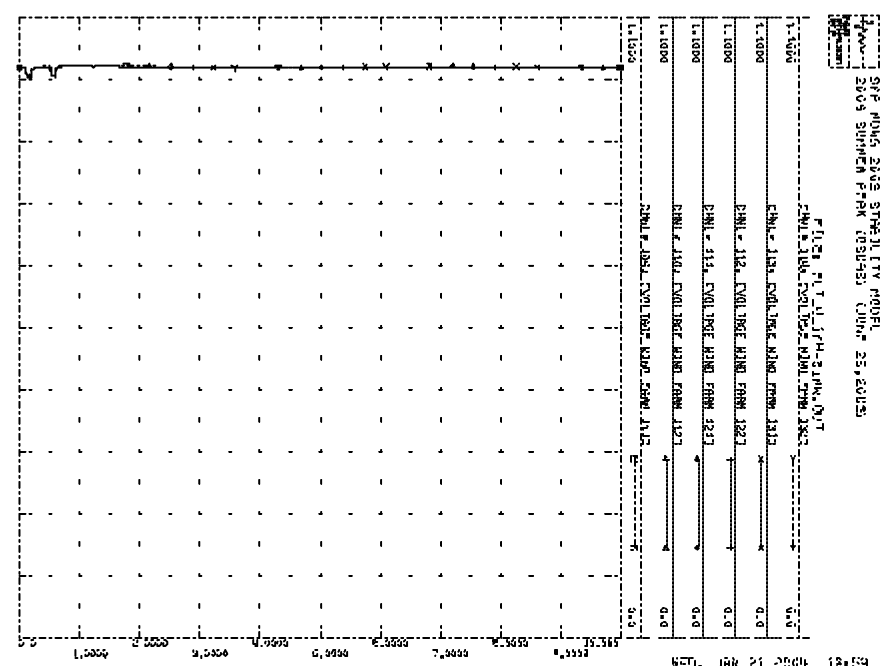
FLT_1 WIND FARM VOLTAGES



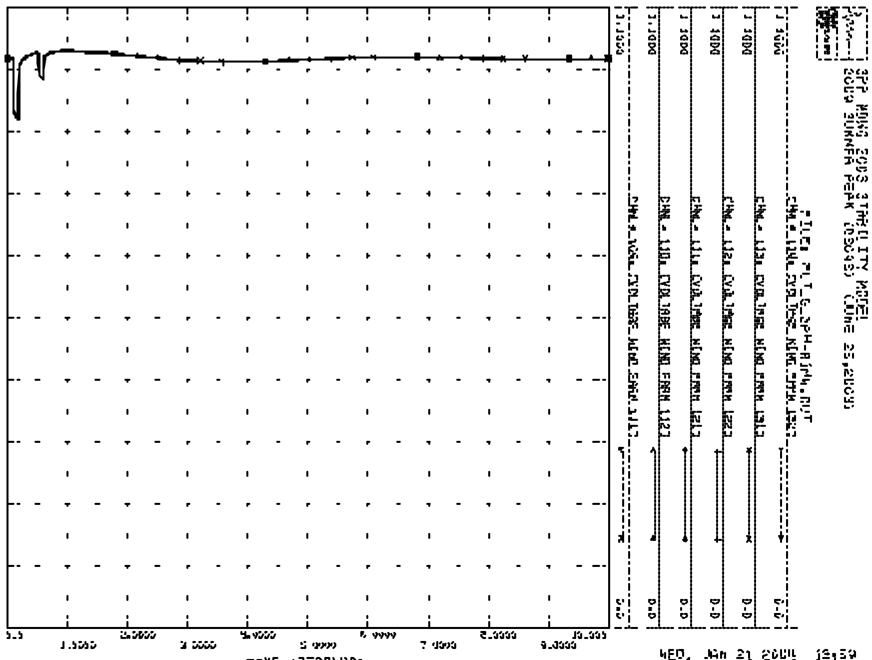
FLT_2 WIND FARM VOLTAGES



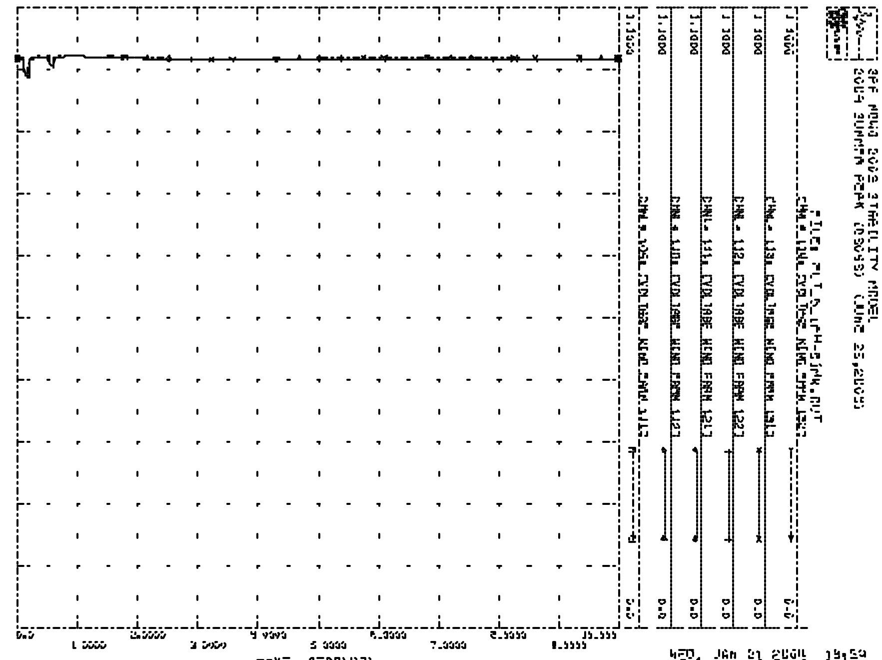
FLT_3 WIND FARM VOLTAGES



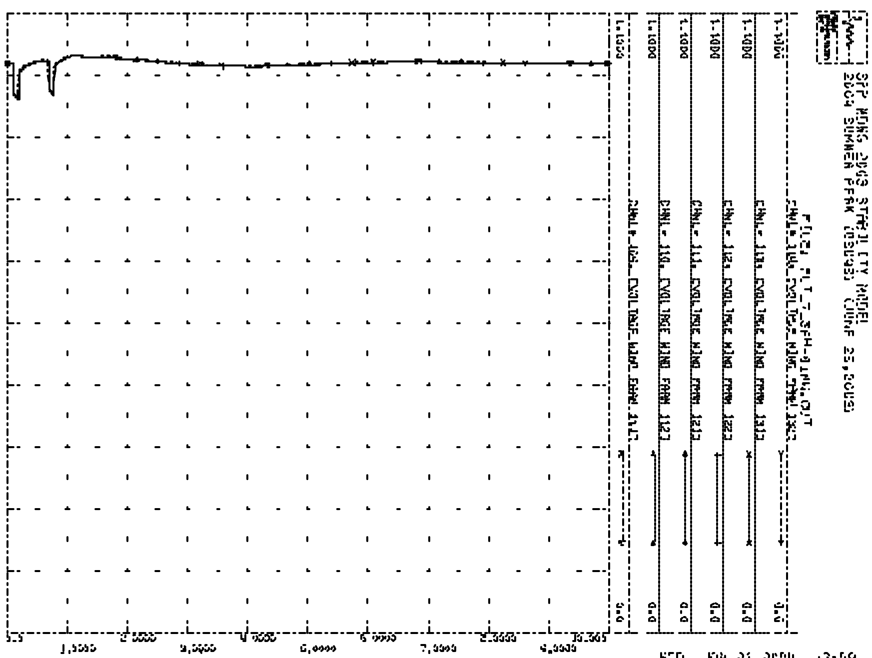
FLT_4 WIND FARM VOLTAGES



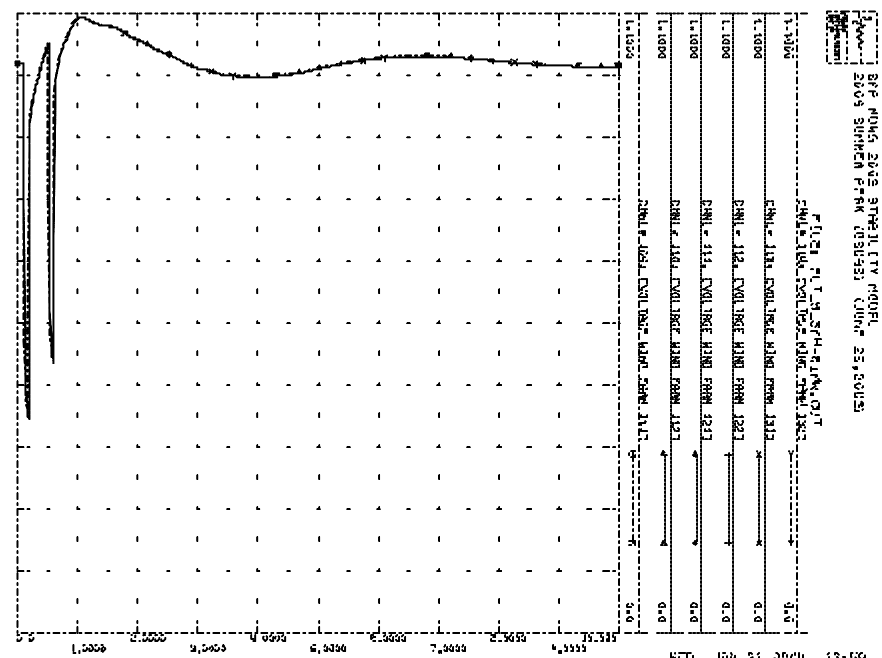
FLT_5 WIND FARM VOLTAGES



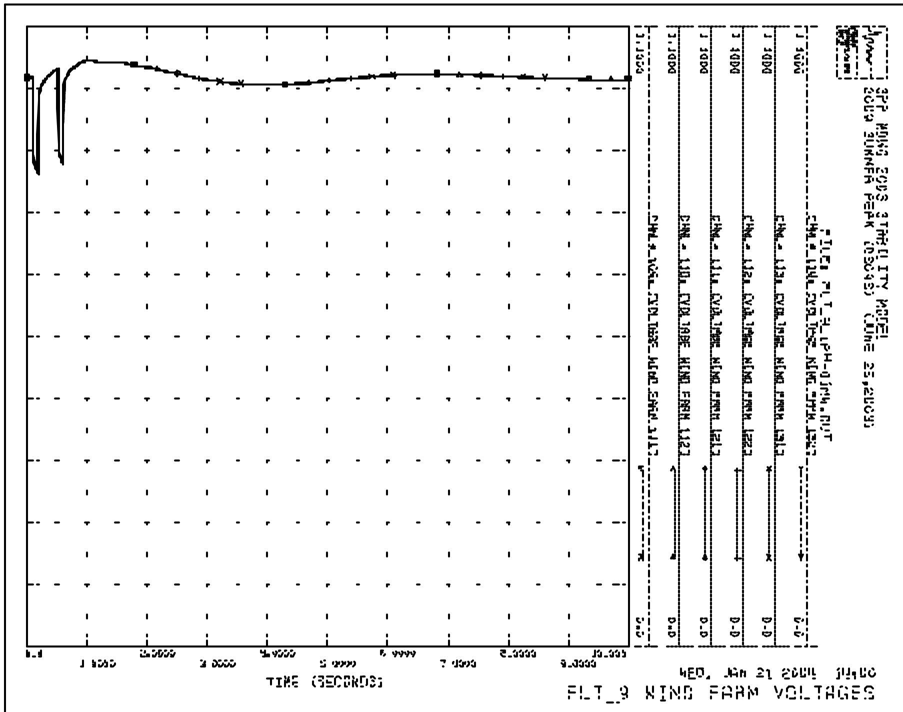
FLT_6 WIND FARM VOLTAGES

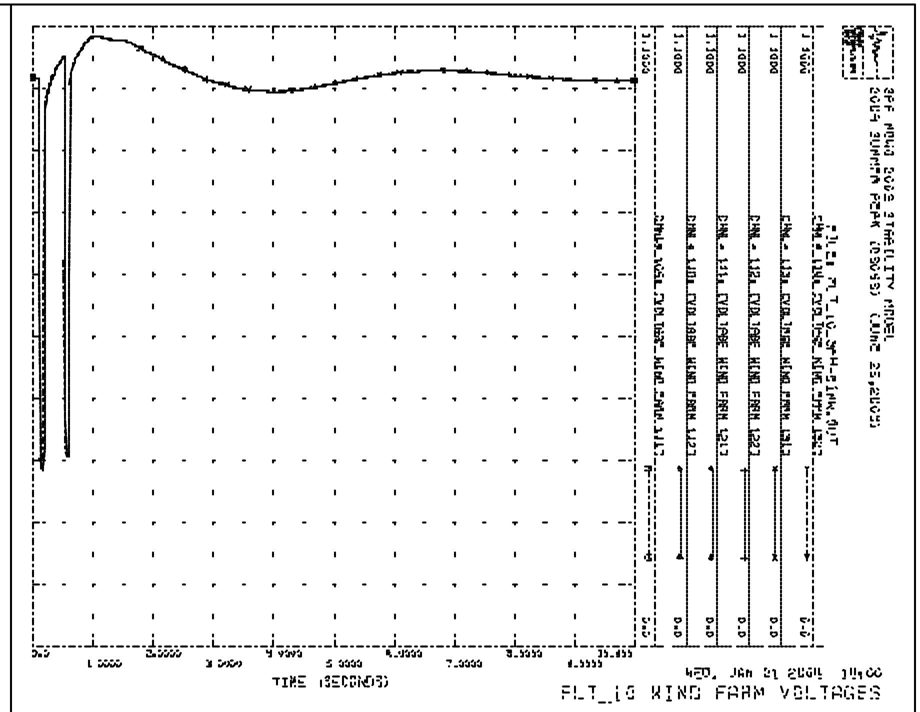


FLT_7 WIND FARM VOLTAGES



FLT_8 WIND FARM VOLTAGES


TIME (SECONDS)
WED, JAN 21 2004 10:00
FLT_9 WIND FARM VOLTAGES


TIME (SECONDS)
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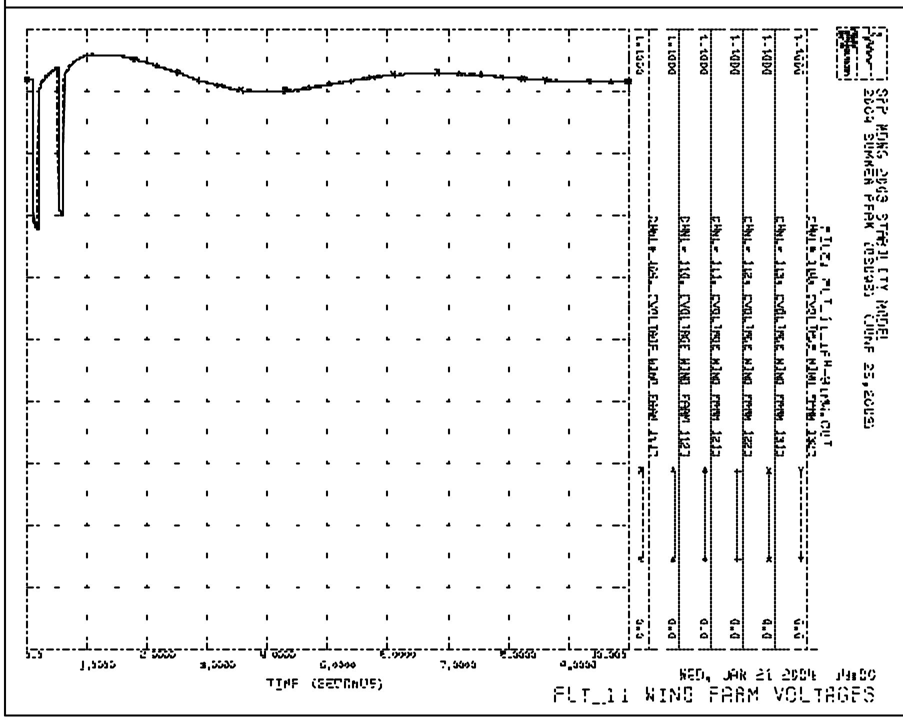
FLT_10 WIND FARM VOLTAGES


TIME (SECONDS)
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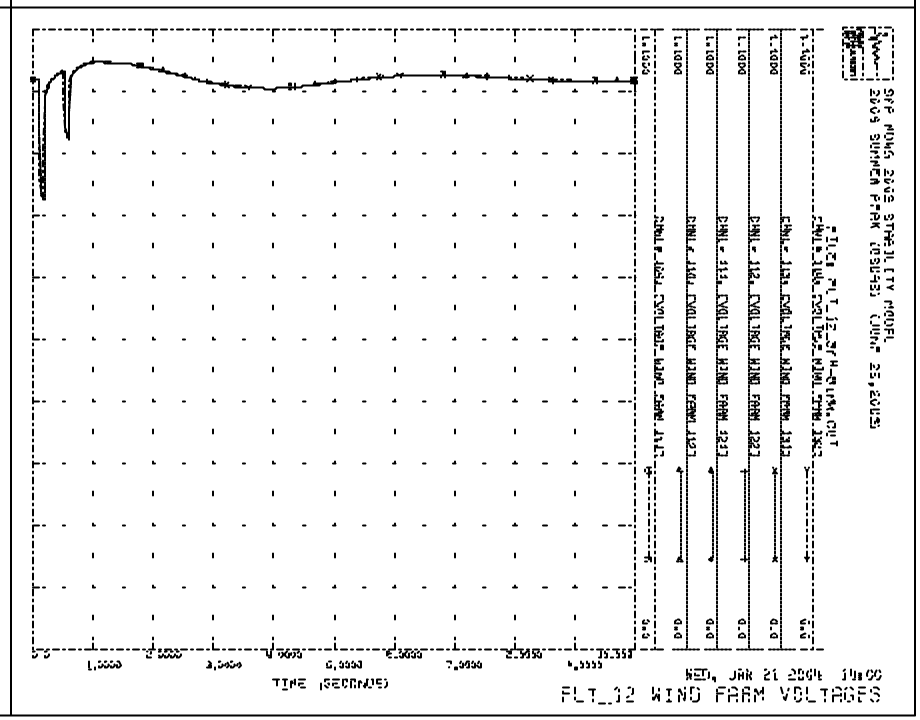
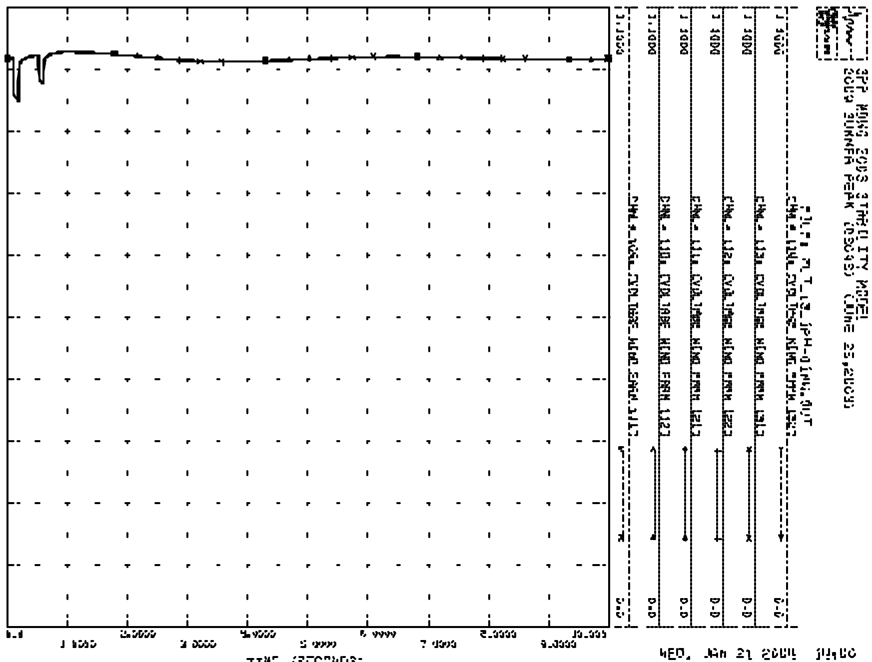
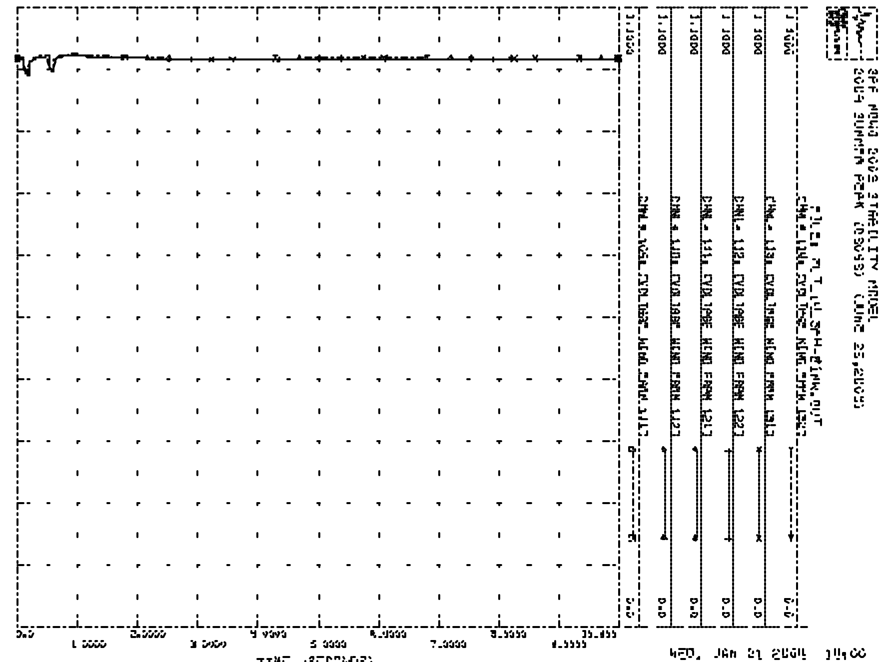
FLT_11 WIND FARM VOLTAGES

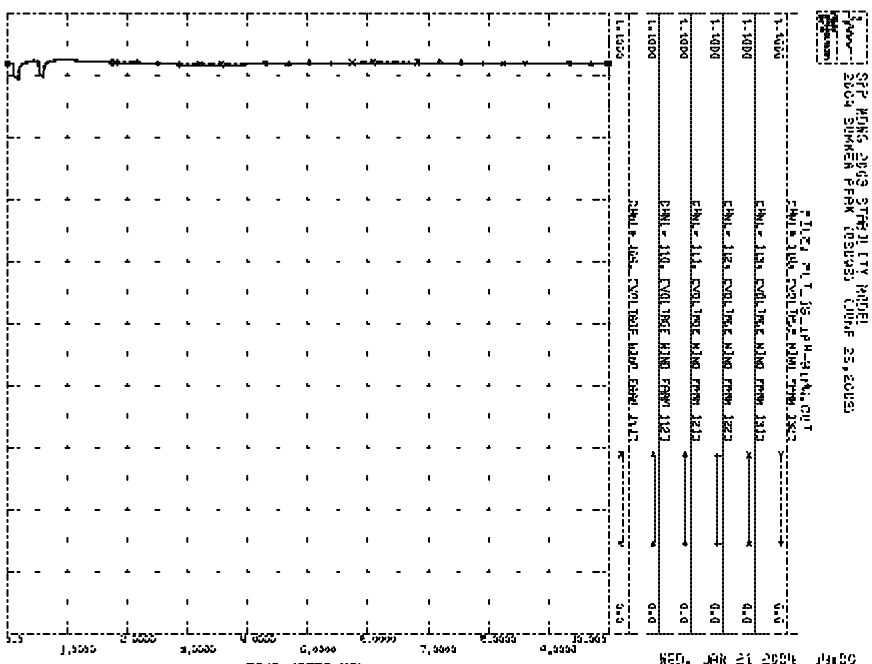

TIME (SECONDS)
WED, JAN 21 2004 10:00
FLT_12 WIND FARM VOLTAGES



FLT_13 WIND FARM VOLTAGES



FLT_14 WIND FARM VOLTAGES



FLT_15 WIND FARM VOLTAGES

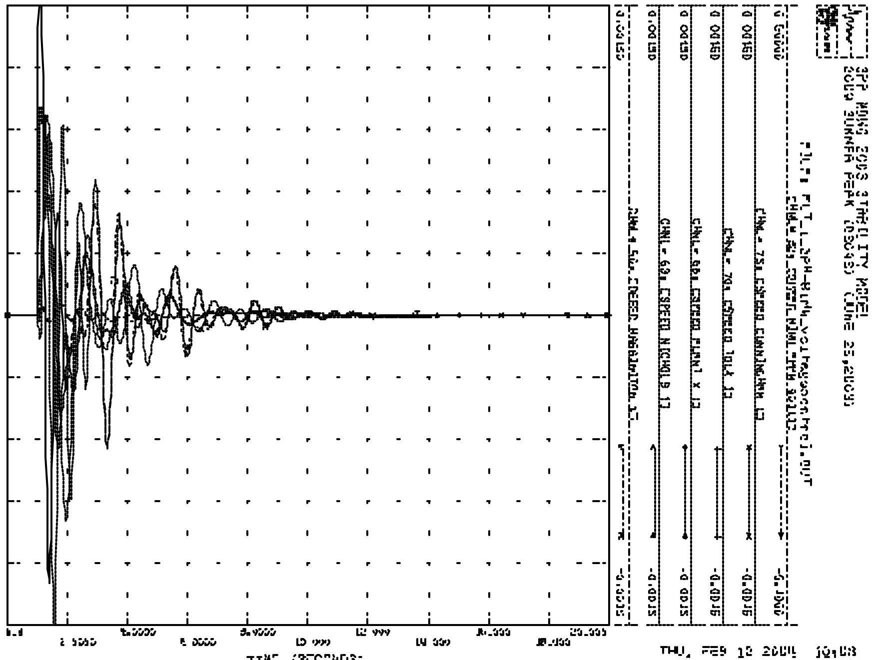
Appendix C

Plots of Fault Simulations

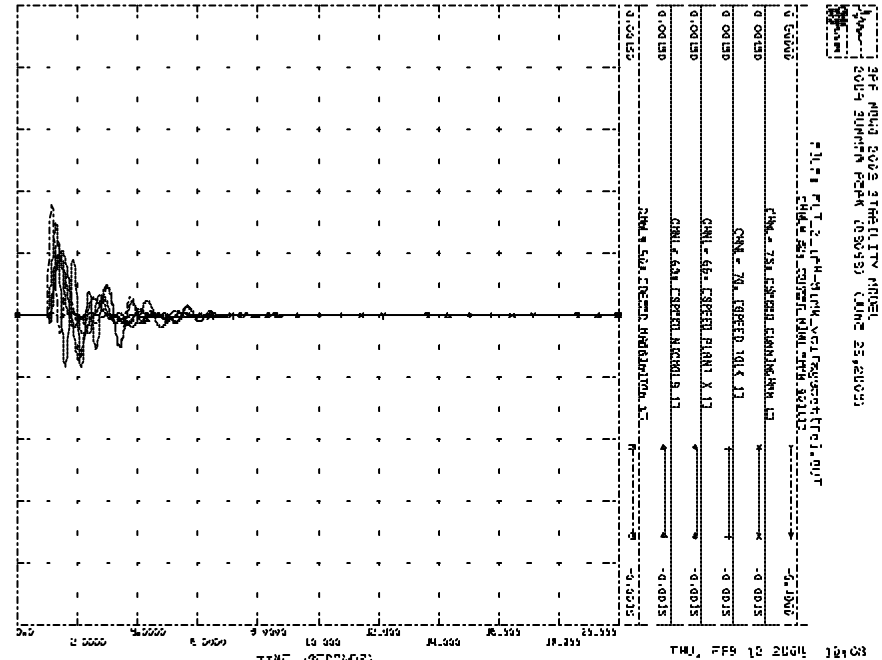
Section 1

Plots of Wind Farm generator equivalent #1 speed during faults overlayed
With other SPS generator speeds

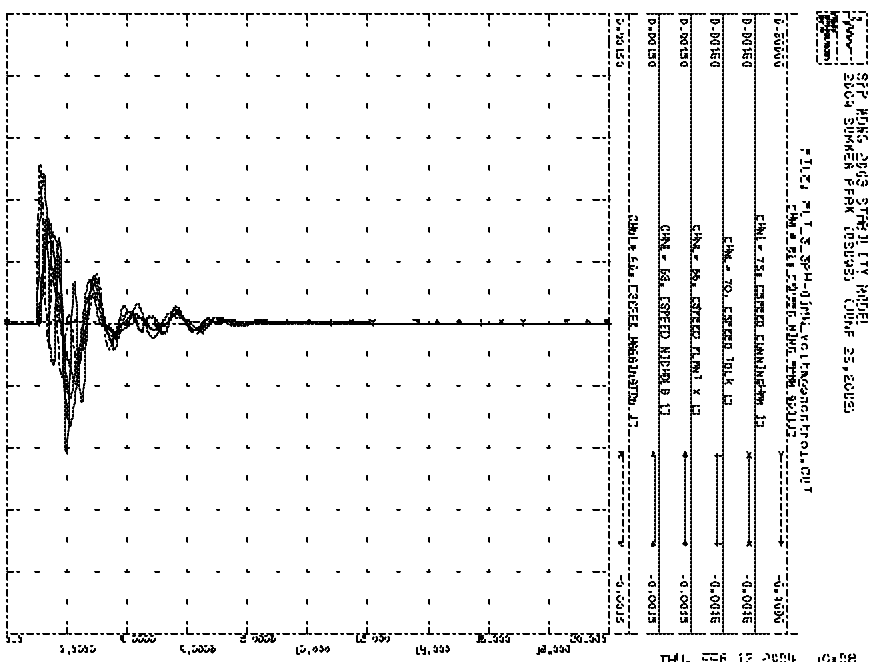
Scenario: Wind Farm at 81MW output and Voltage Control enabled



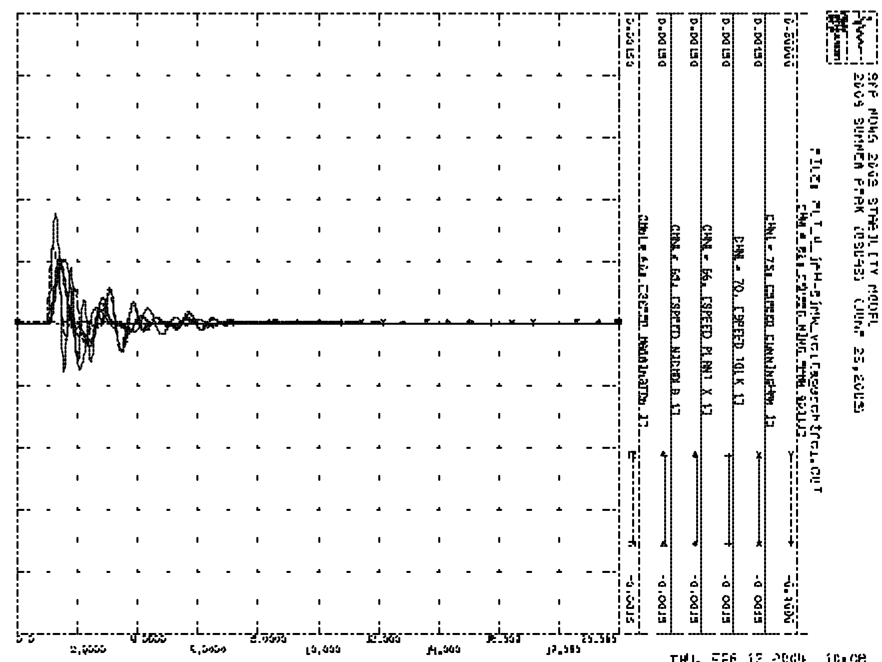
FLT_1 MACHINE SPEEDS



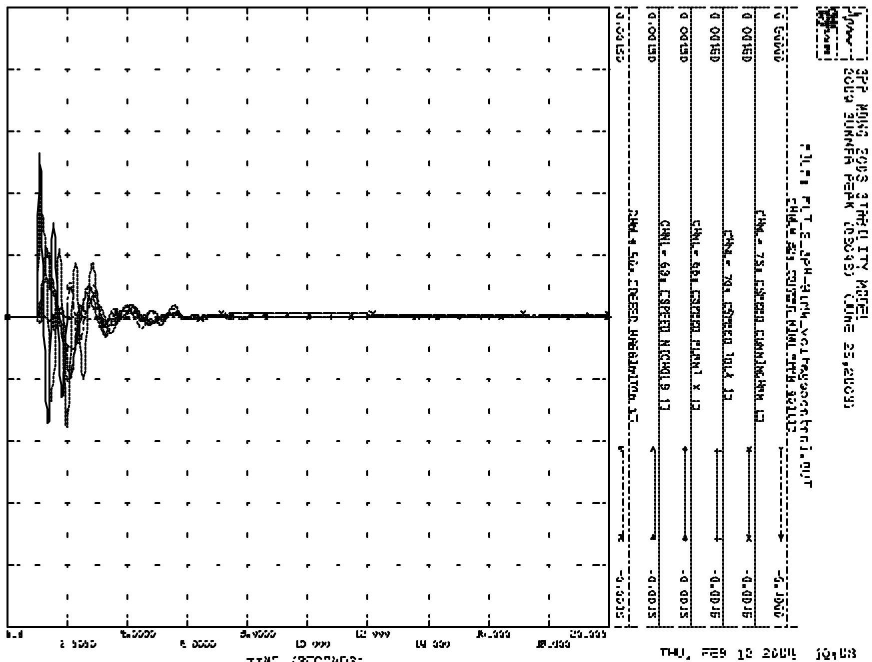
FLT_2 MACHINE SPEEDS



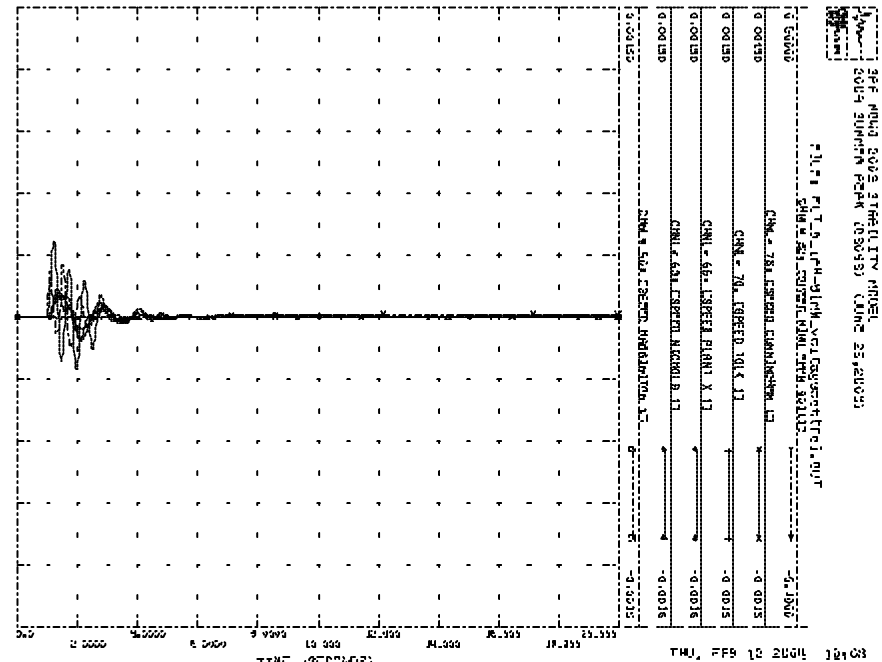
FLT_3 MACHINE SPEEDS



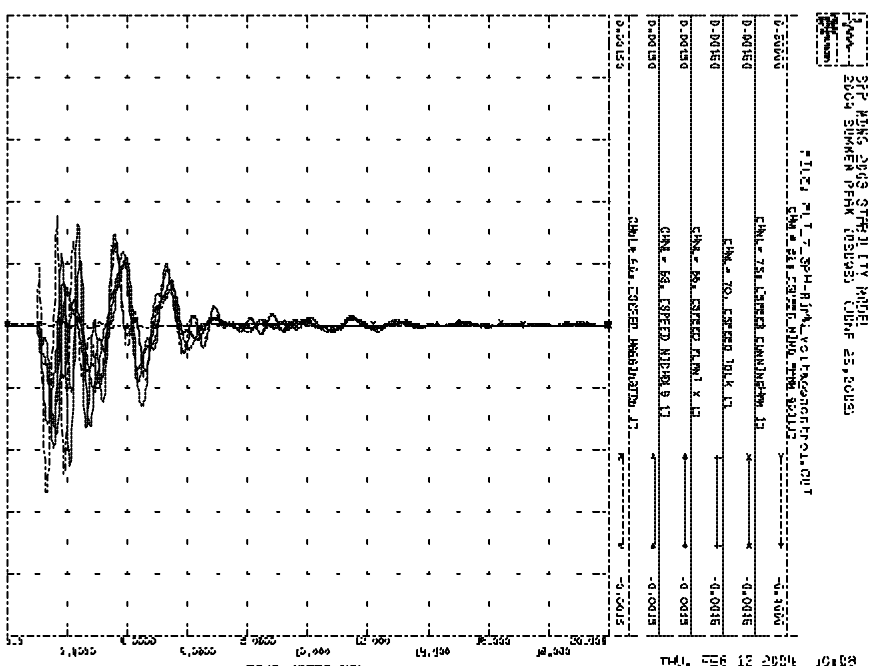
FLT_4 MACHINE SPEEDS



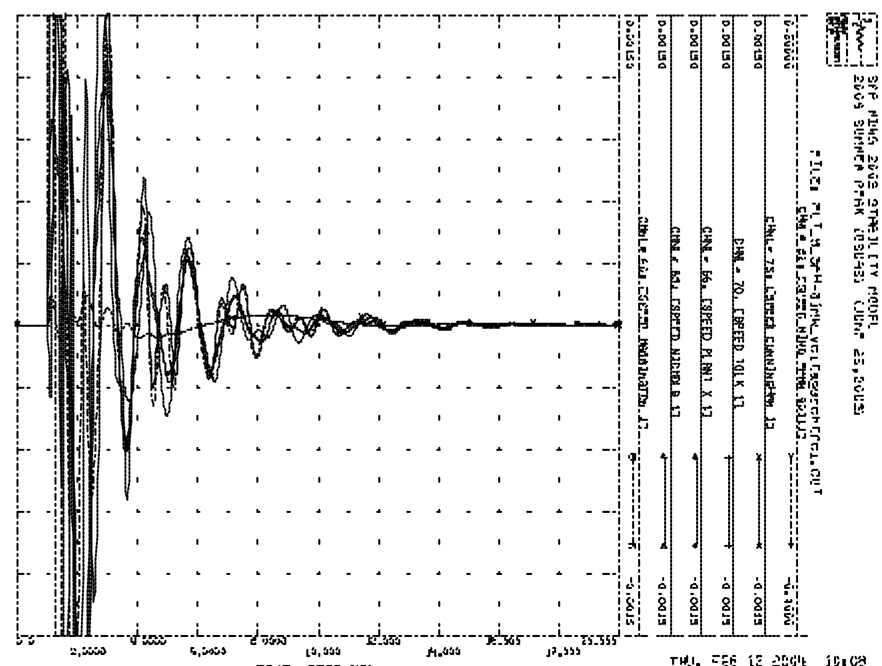
FLT_5 MACHINE SPEEDS



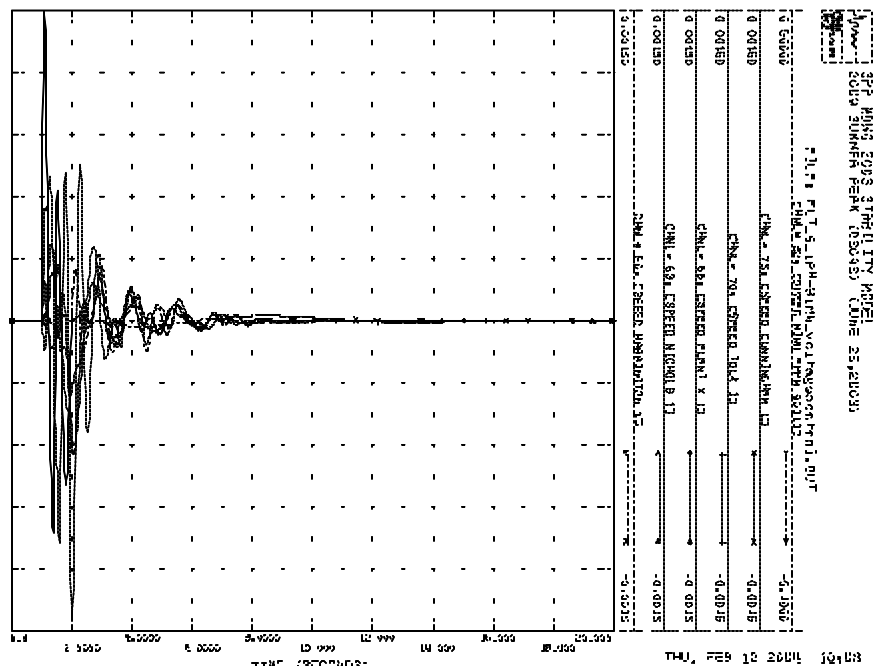
FLT_6 MACHINE SPEEDS



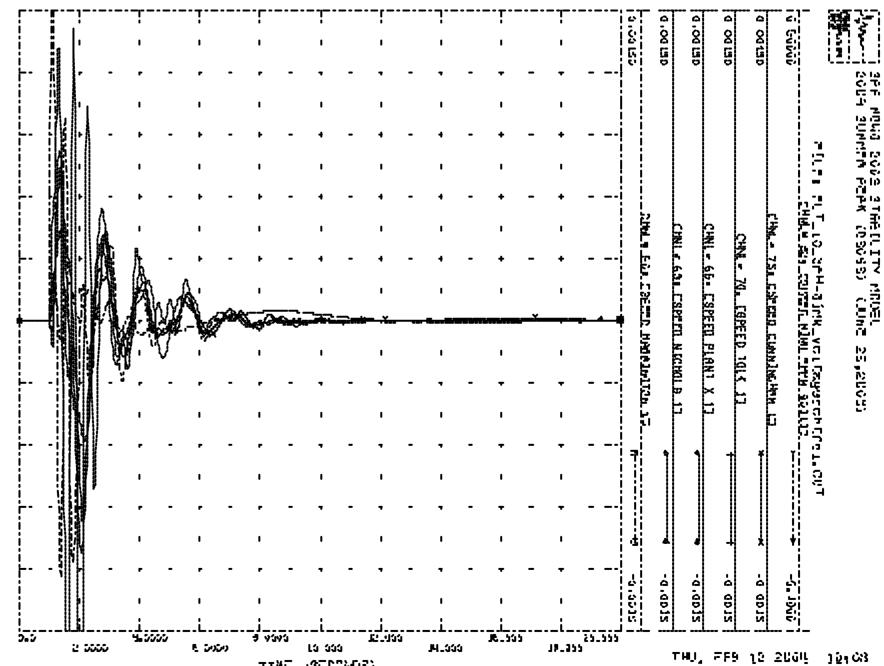
FLT_7 MACHINE SPEEDS



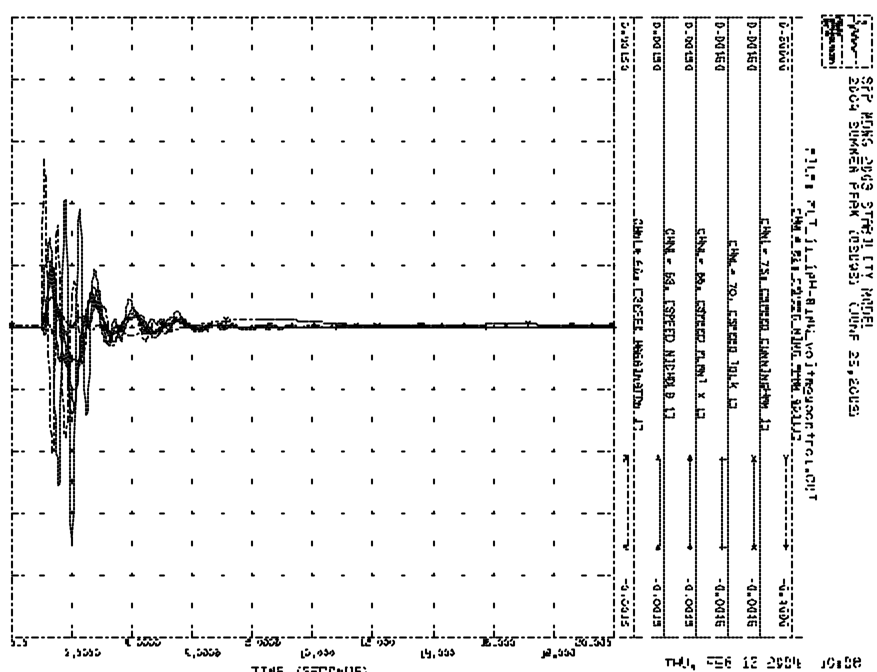
FLT_8 MACHINE SPEEDS



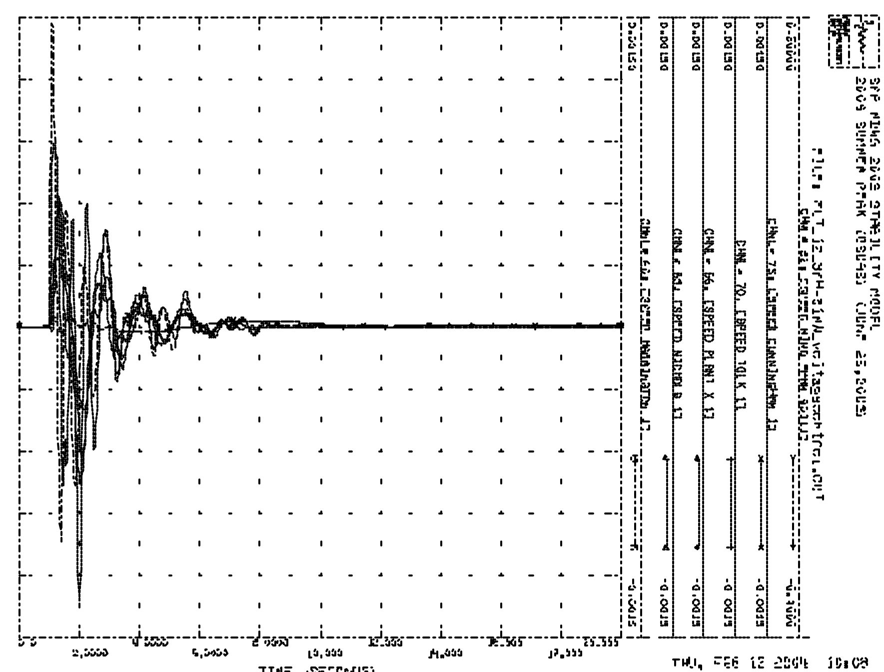
FLT_9 MACHINE SPEEDS



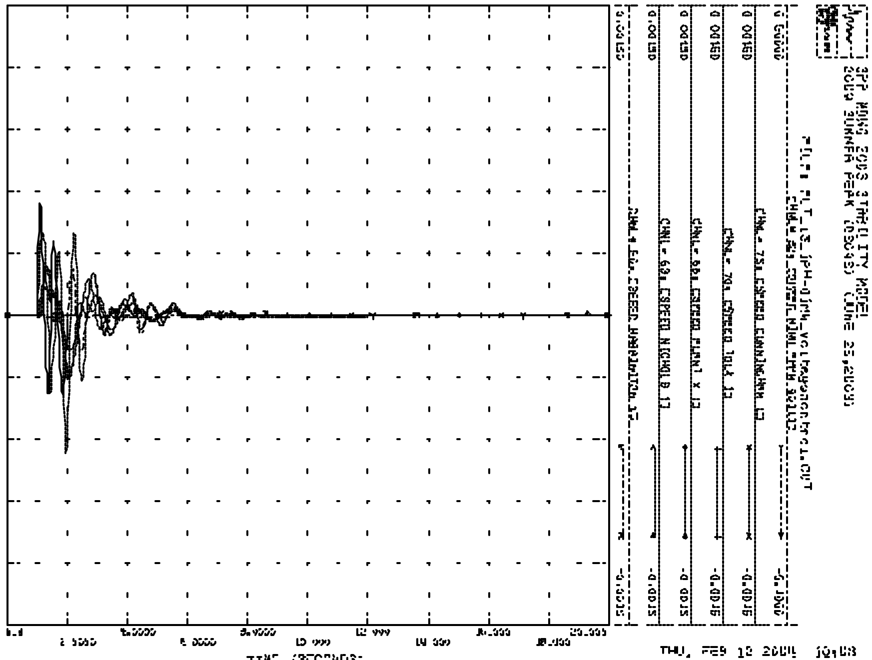
FLT_10 MACHINE SPEEDS



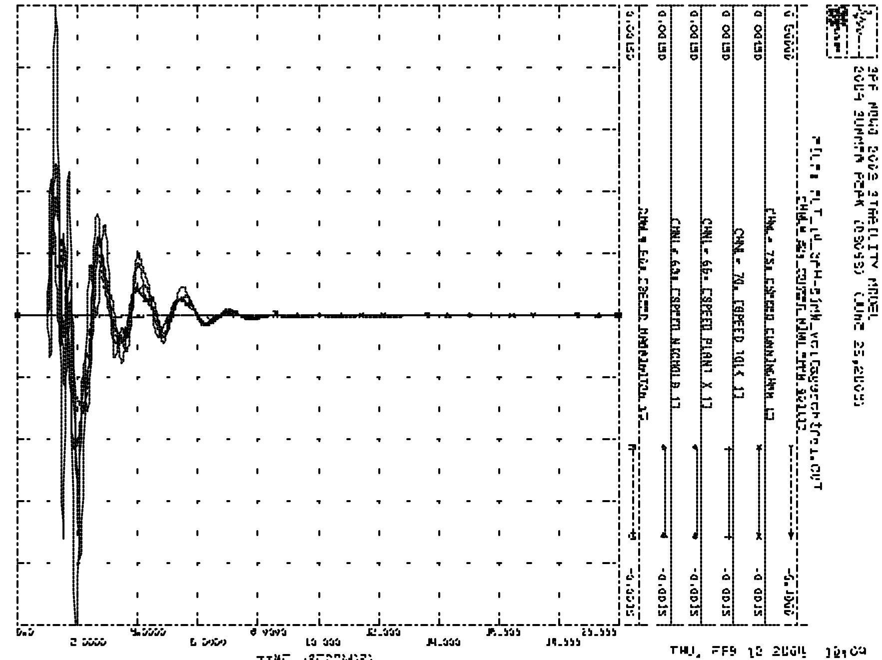
FLT_11 MACHINE SPEEDS



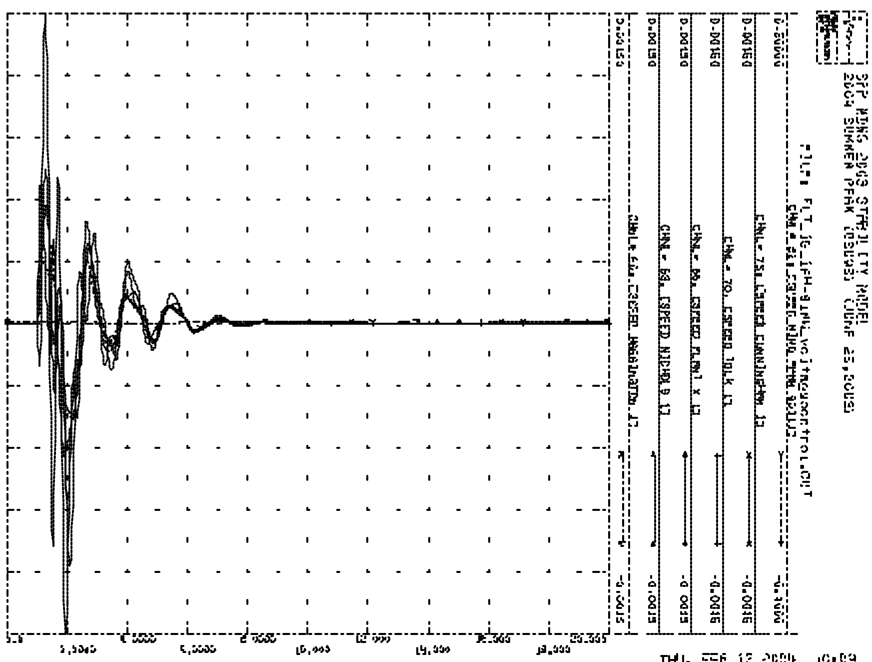
FLT_12 MACHINE SPEEDS



FLT_13 MACHINE SPEEDS



FLT_14 MACHINE SPEEDS



FLT_15 MACHINE SPEEDS

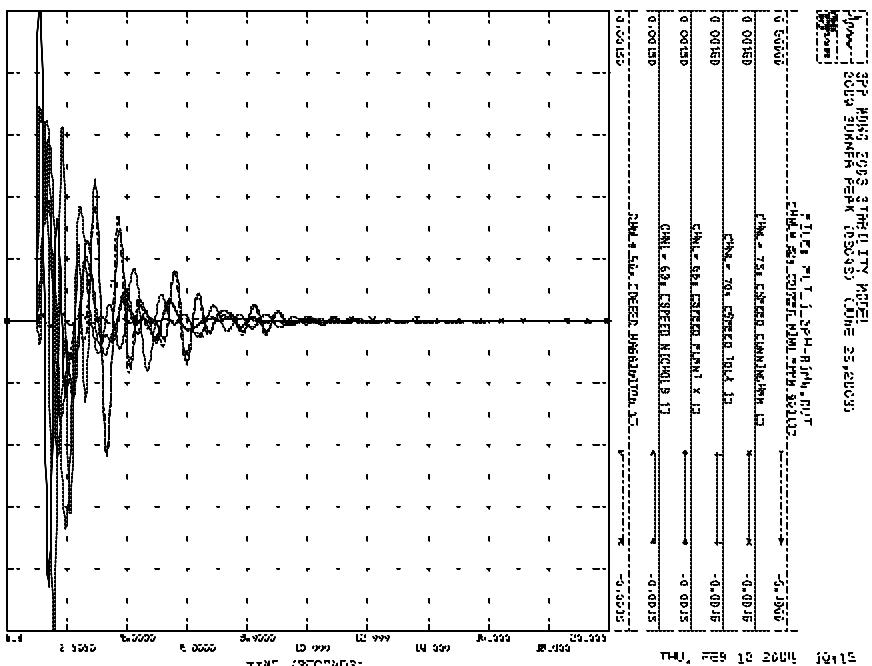
Appendix C

Plots of Fault Simulations

Section 2

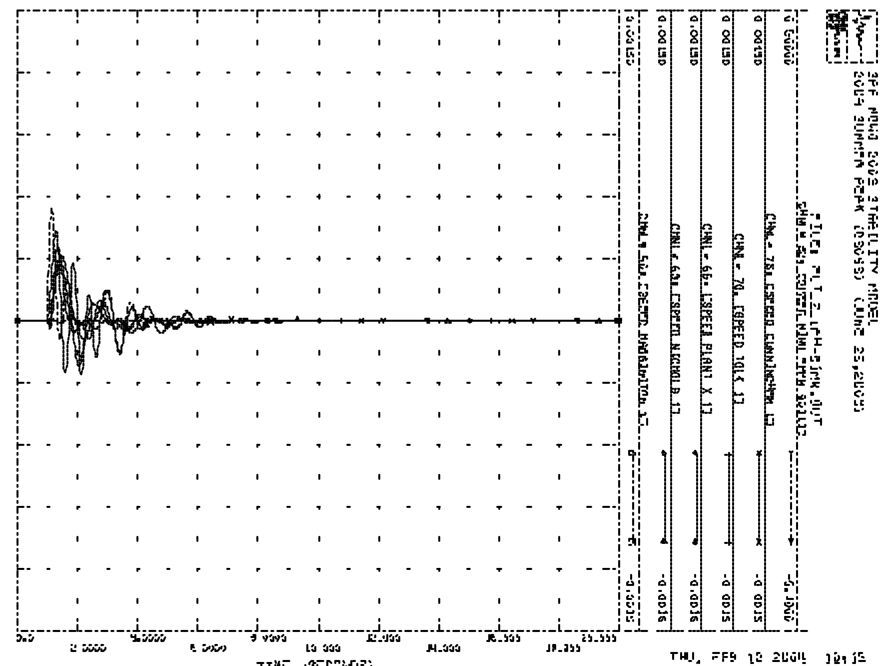
Plots of Wind Farm generator equivalent #1 speeds during faults overlayed With other SPS generator speeds

Scenario: Wind Farm at 81MW output and Power Factor Control enabled



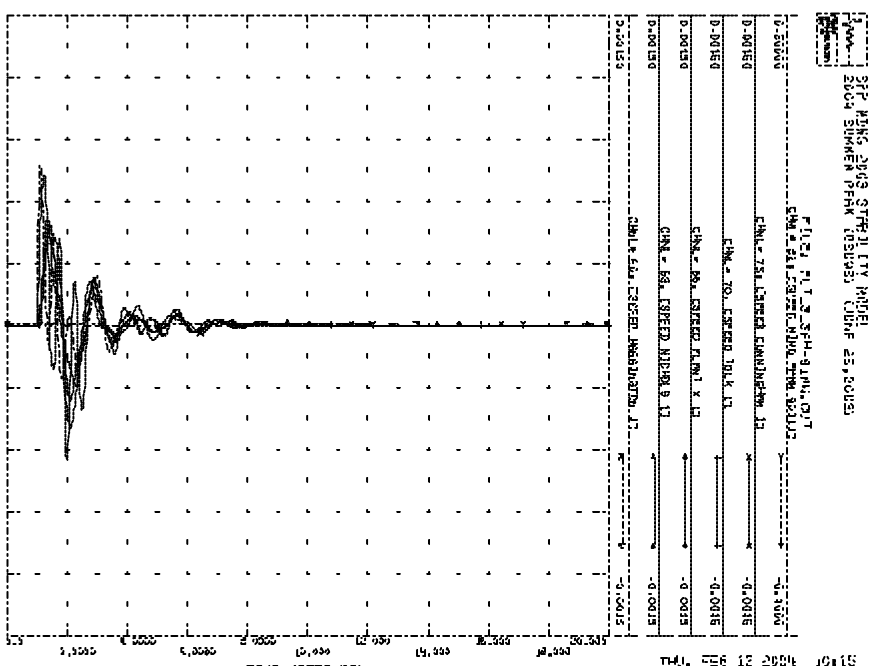
THU, FEB 12 2004 10:15

FLT_1 MACHINE SPEEDS



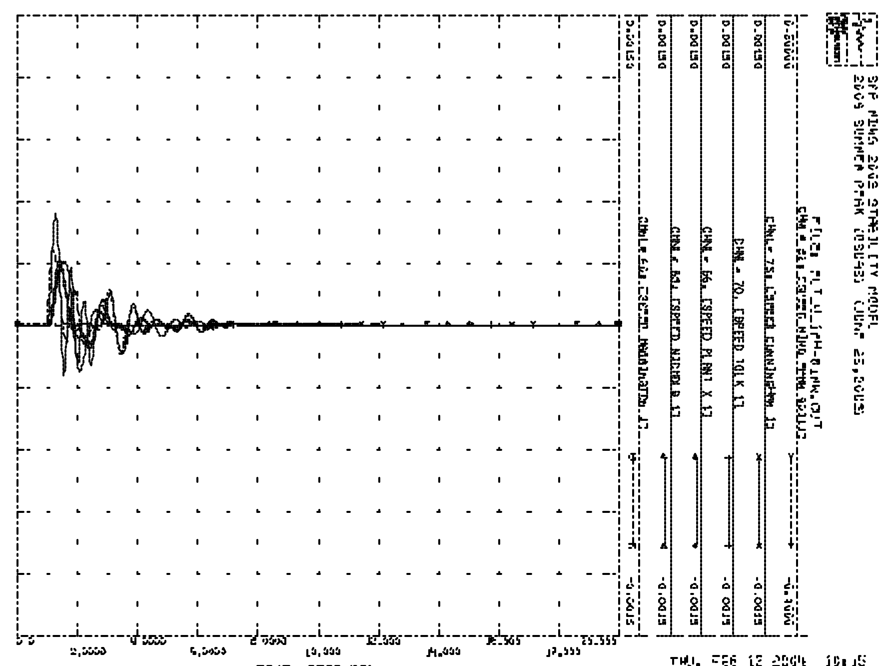
THU, FEB 12 2004 10:15

FLT_2 MACHINE SPEEDS



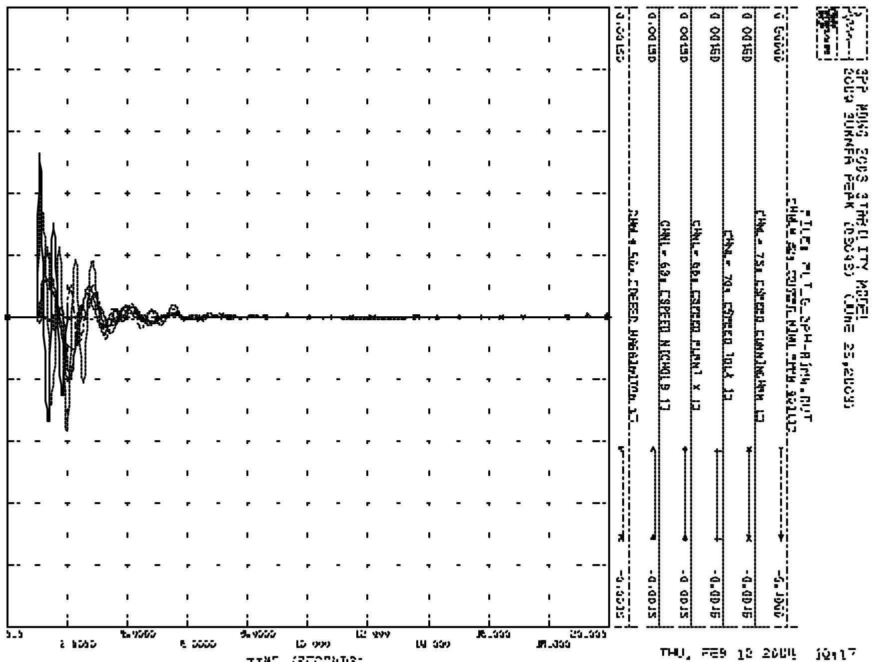
THU, FEB 12 2004 10:15

FLT_3 MACHINE SPEEDS

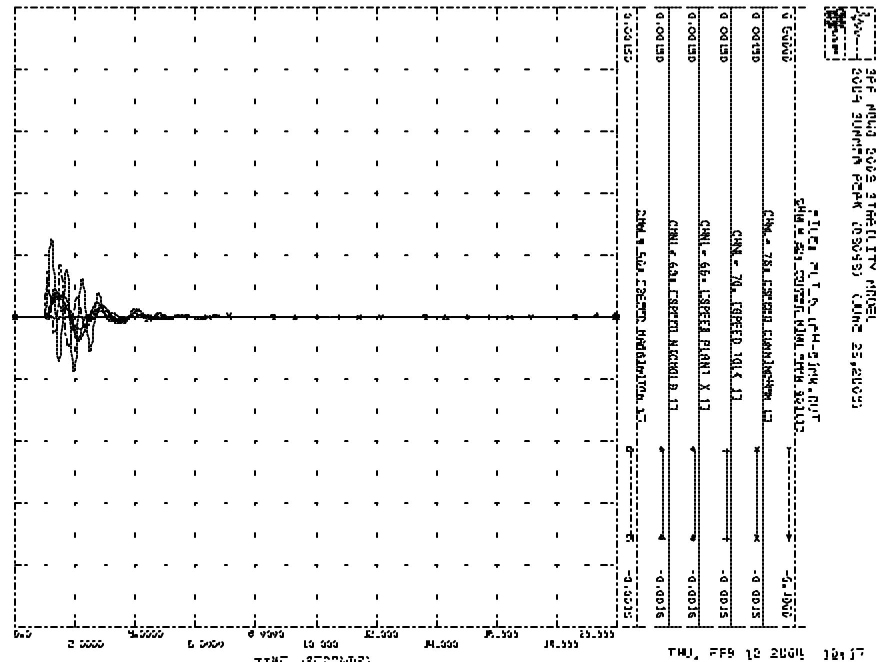


THU, FEB 12 2004 10:15

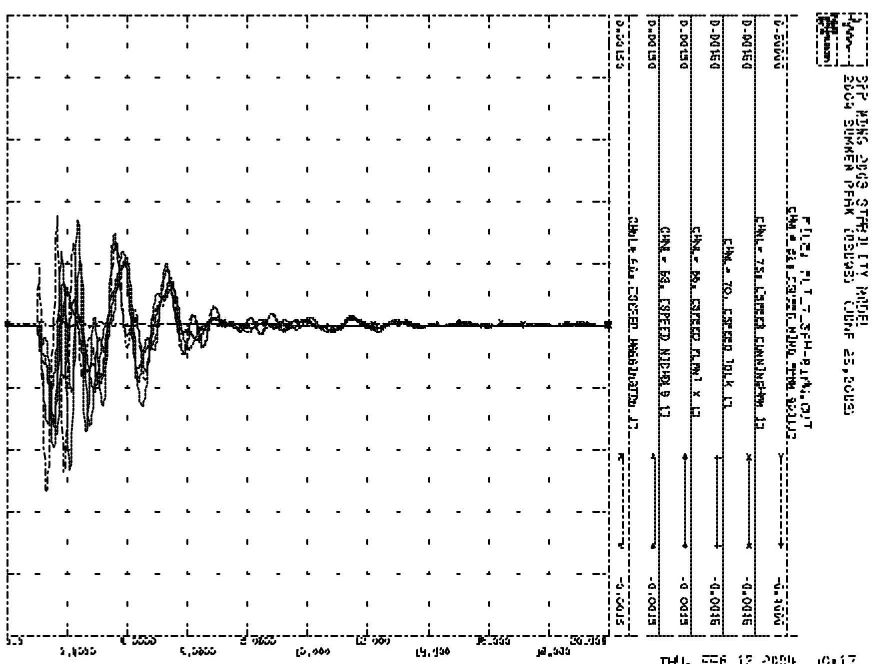
FLT_4 MACHINE SPEEDS



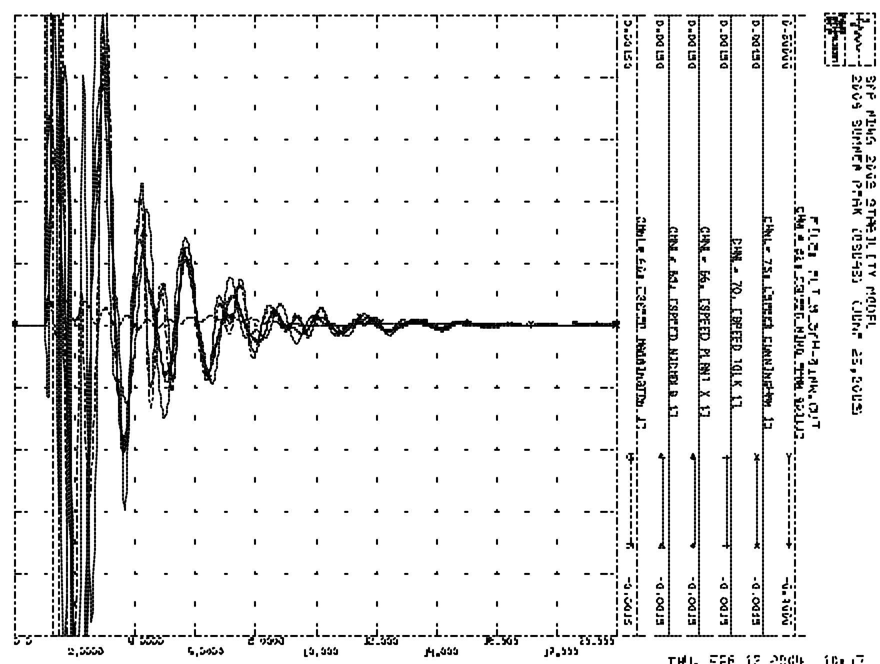
FLT_5 MACHINE SPEEDS



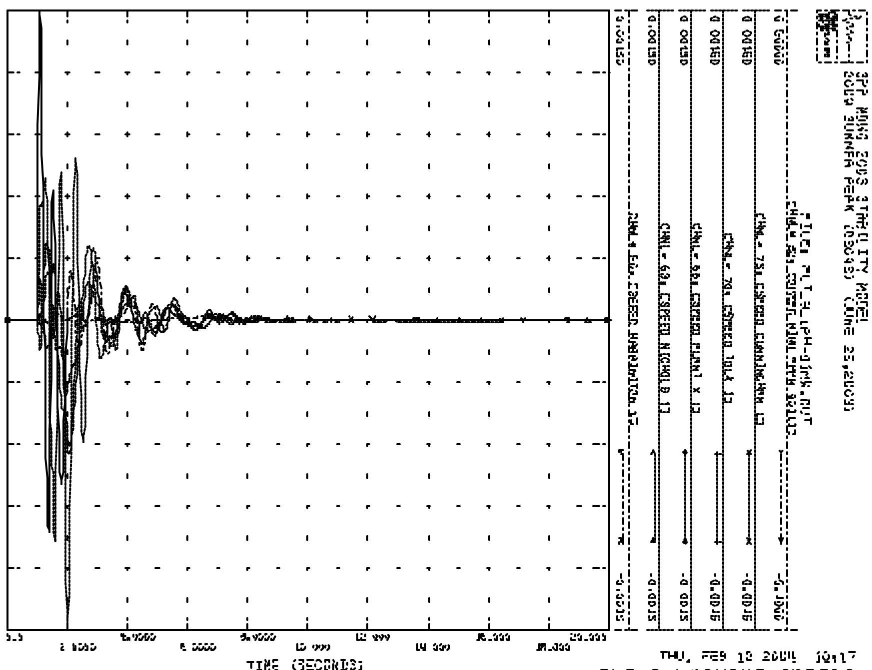
FLT_6 MACHINE SPEEDS



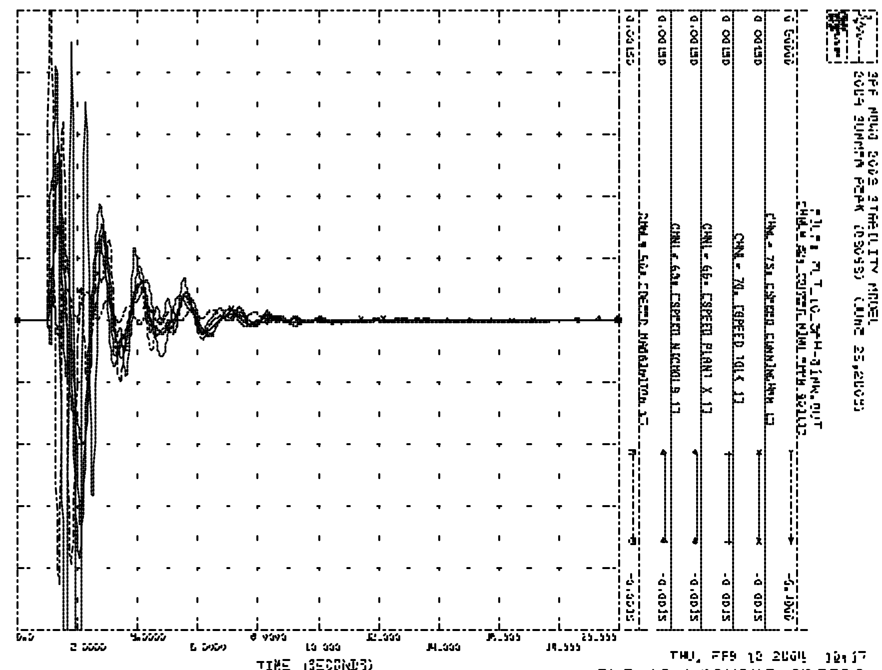
FLT_7 MACHINE SPEEDS



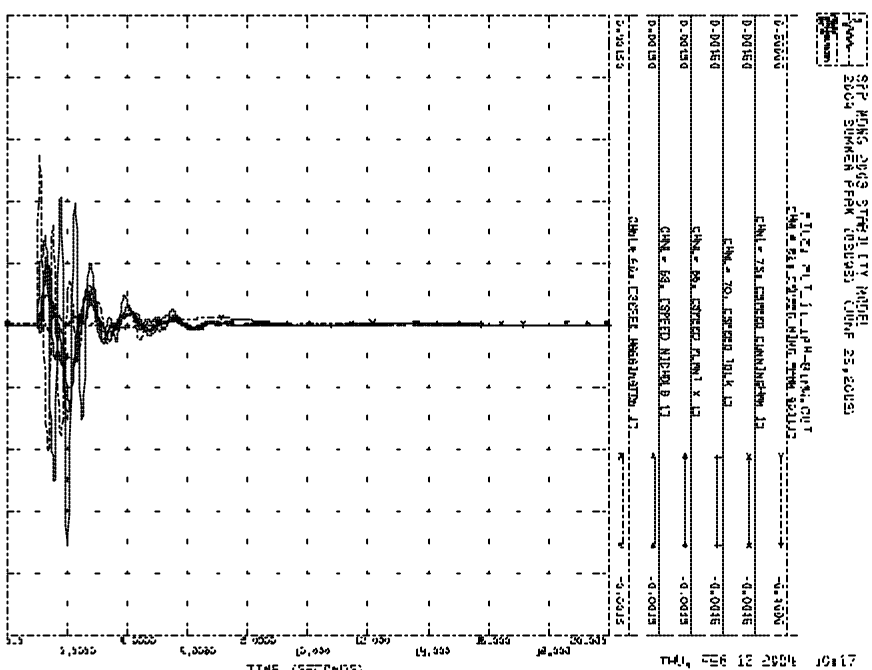
FLT_8 MACHINE SPEEDS



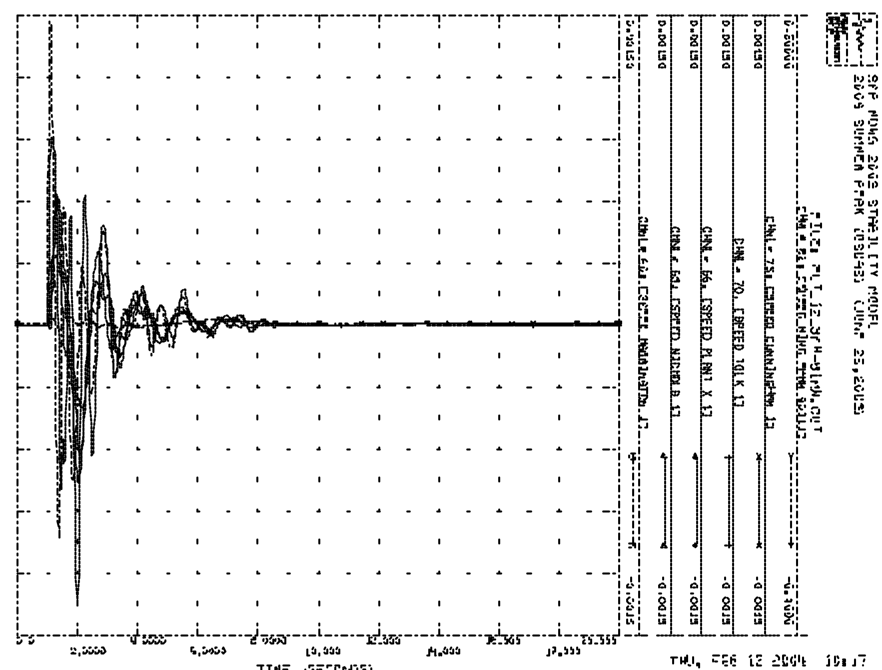
FLT_9 MACHINE SPEEDS



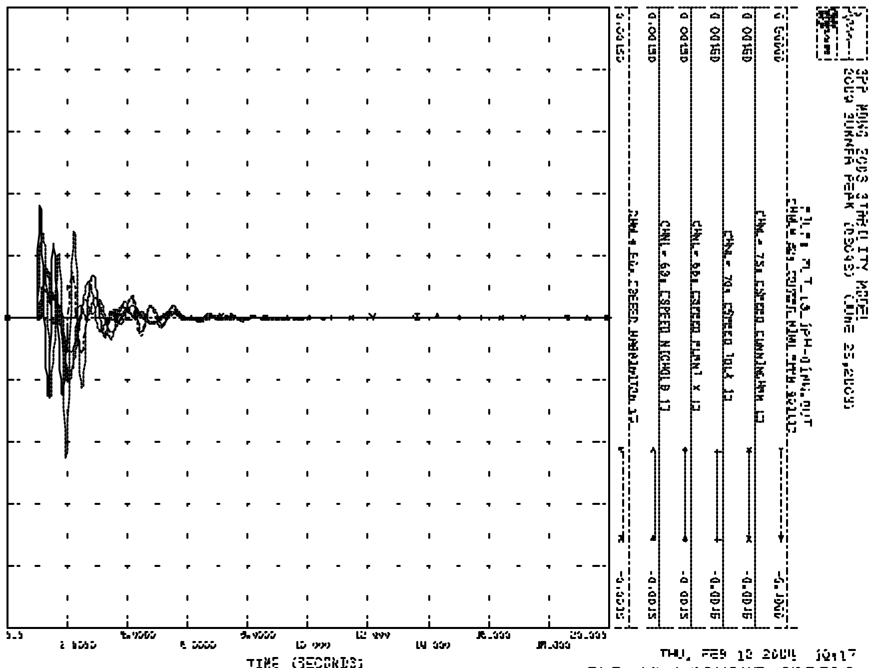
FLT_10 MACHINE SPEEDS



FLT_11 MACHINE SPEEDS



FLT_12 MACHINE SPEEDS



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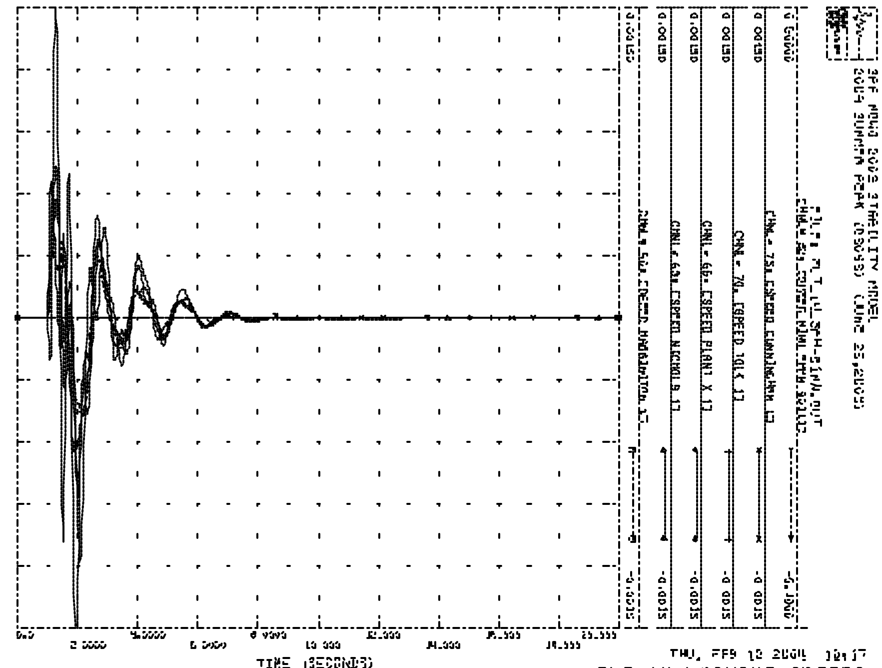
FLT_13 MACHINE SPEEDS



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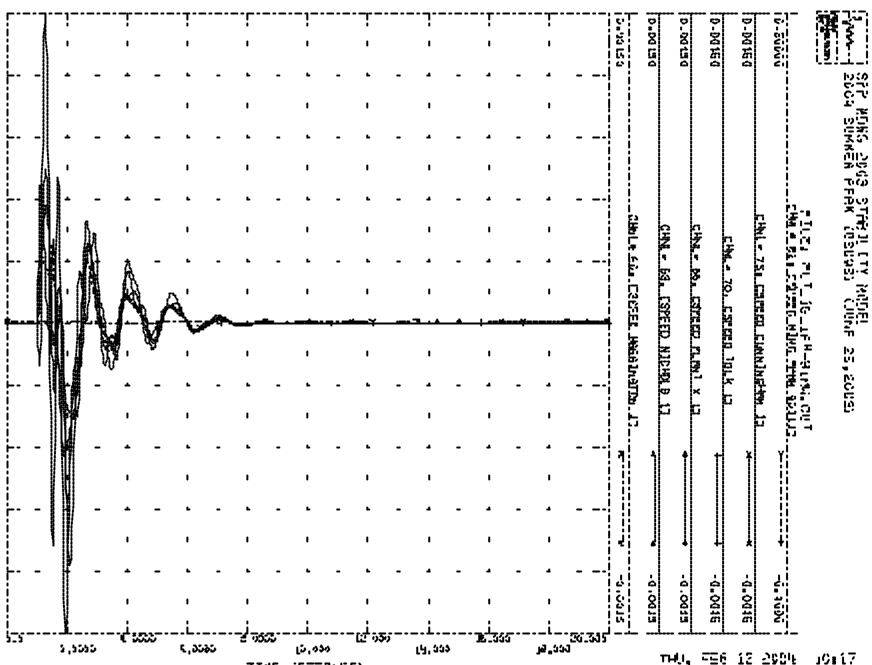
FLT_14 MACHINE SPEEDS



THU, FEB 12 2004 10:17

FLT_15 MACHINE SPEEDS

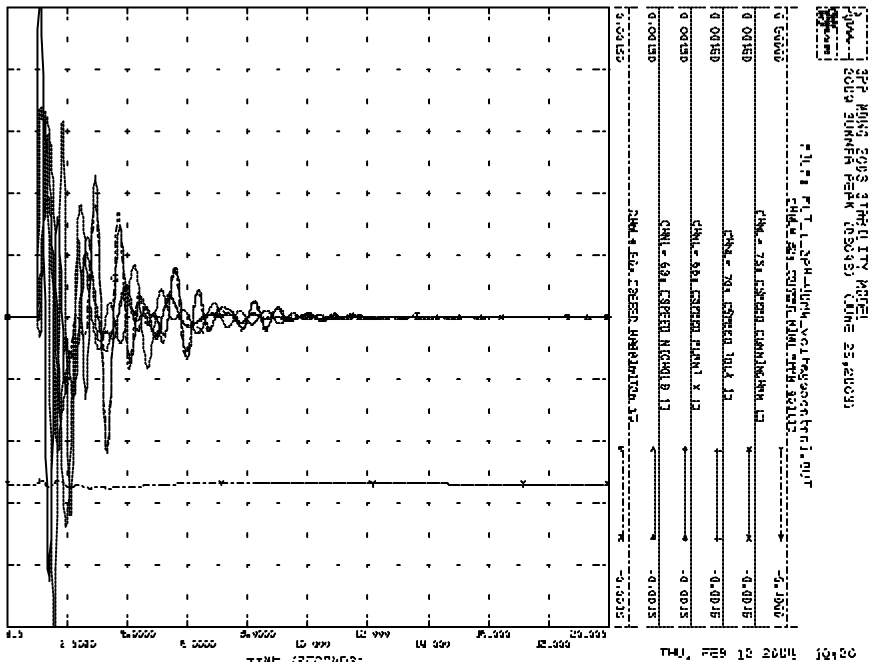
Appendix C

Plots of Fault Simulations

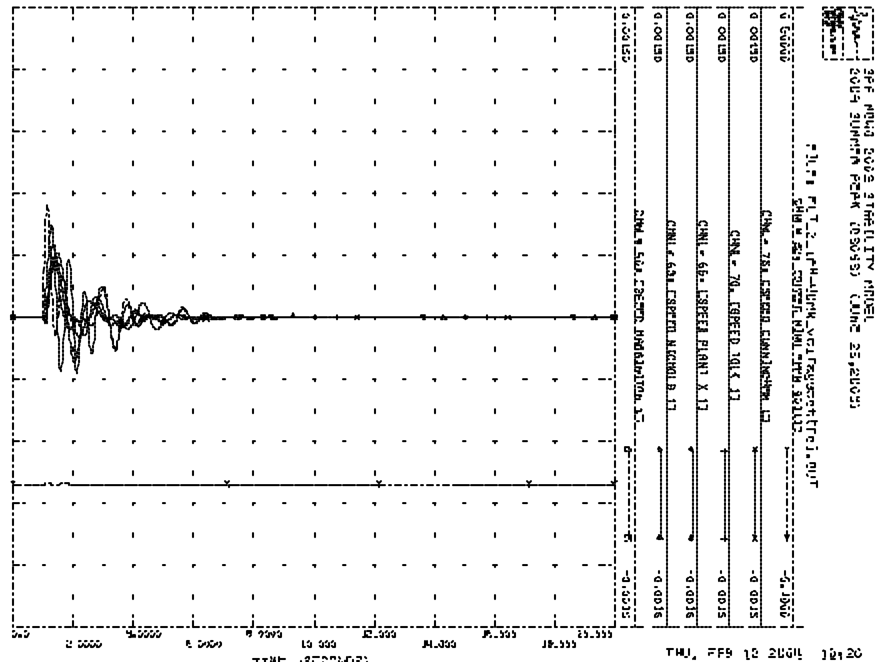
Section 3

Plots of Wind Farm generator equivalent #1 speeds during faults overlayed With other SPS generator speeds

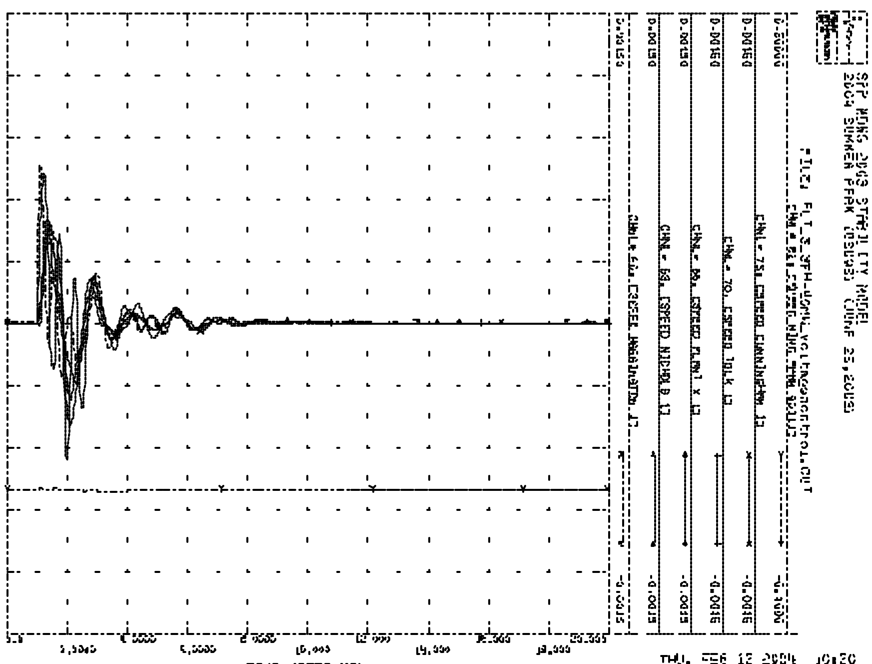
Scenario: Wind Farm at 40.5MW output and Voltage Control enabled



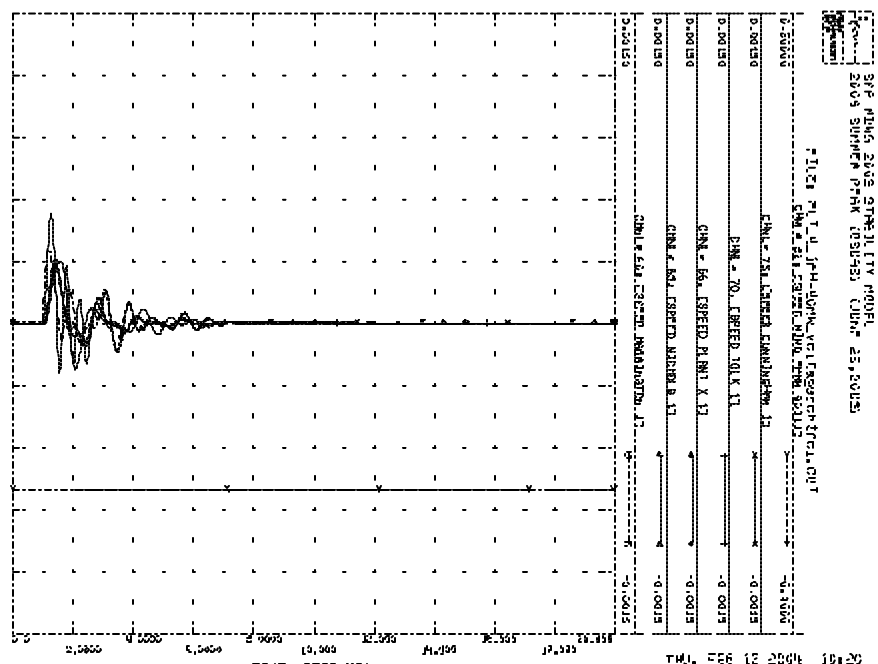
FLT_1 MACHINE SPEEDS



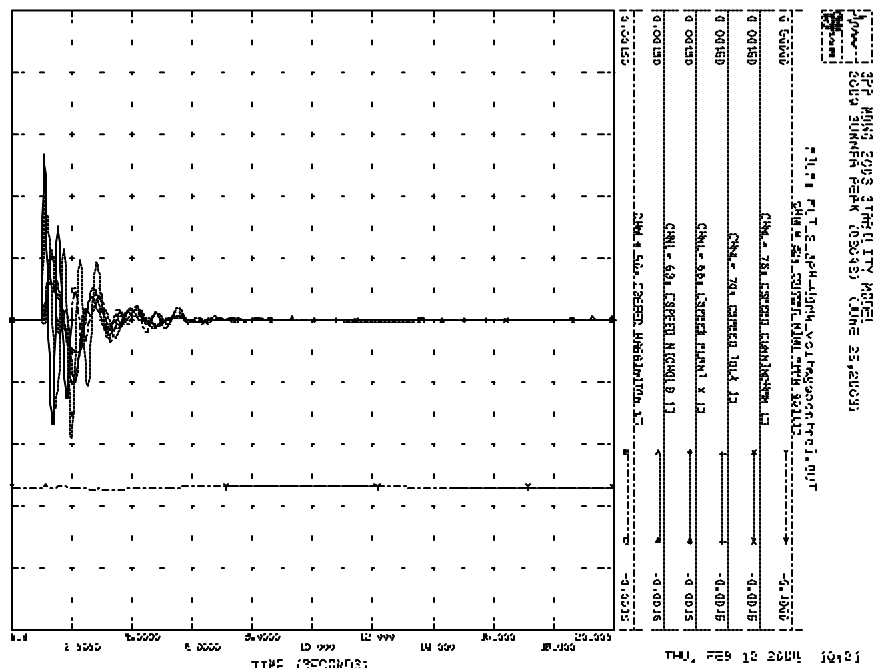
FLT_2 MACHINE SPEEDS



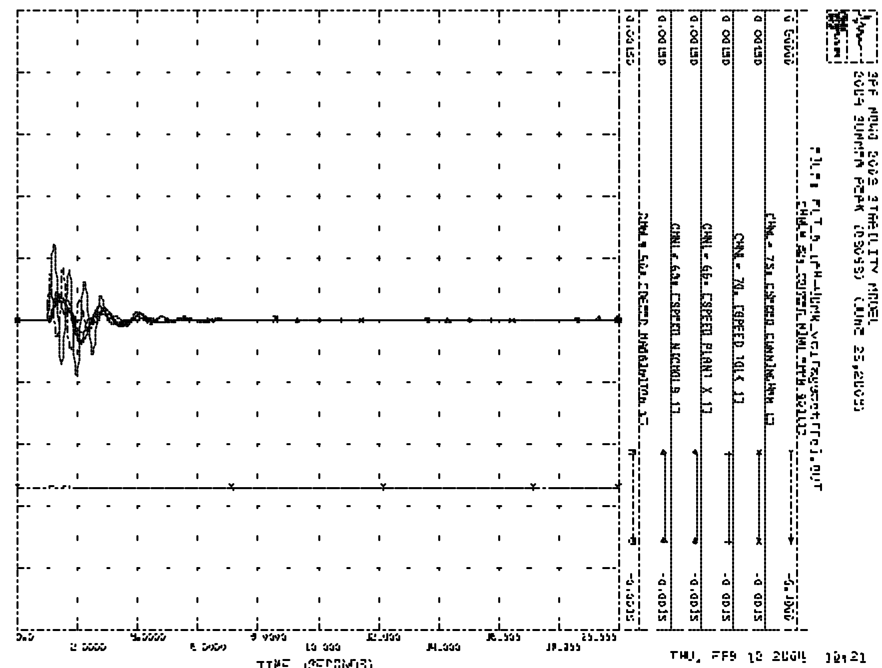
FLT_3 MACHINE SPEEDS



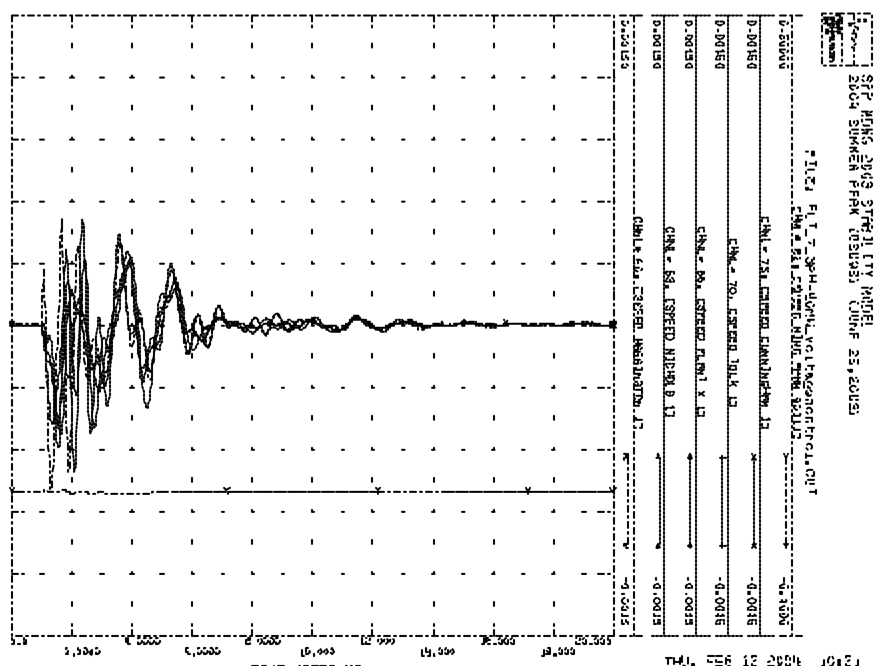
FLT_4 MACHINE SPEEDS



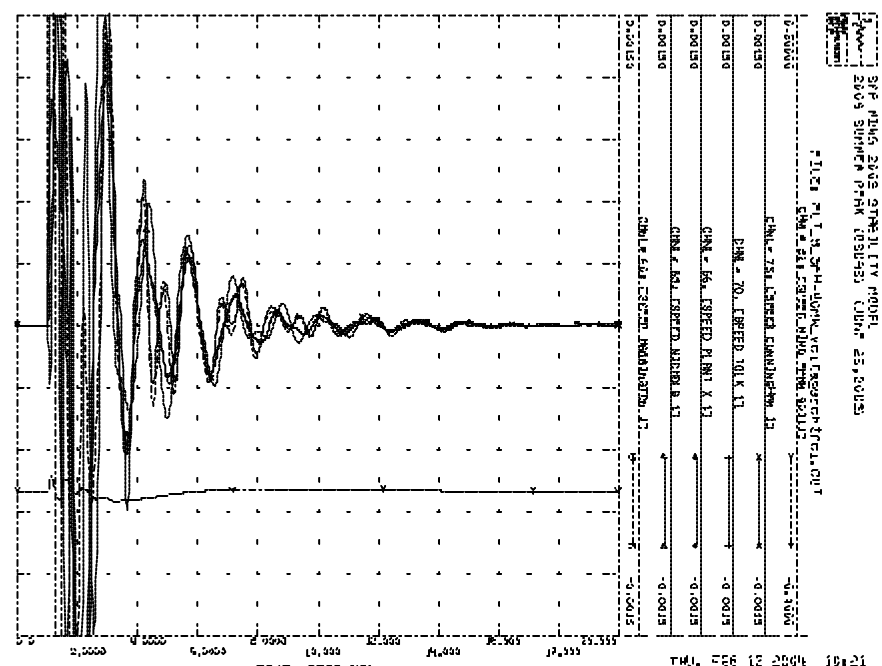
FLT_5 MACHINE SPEEDS



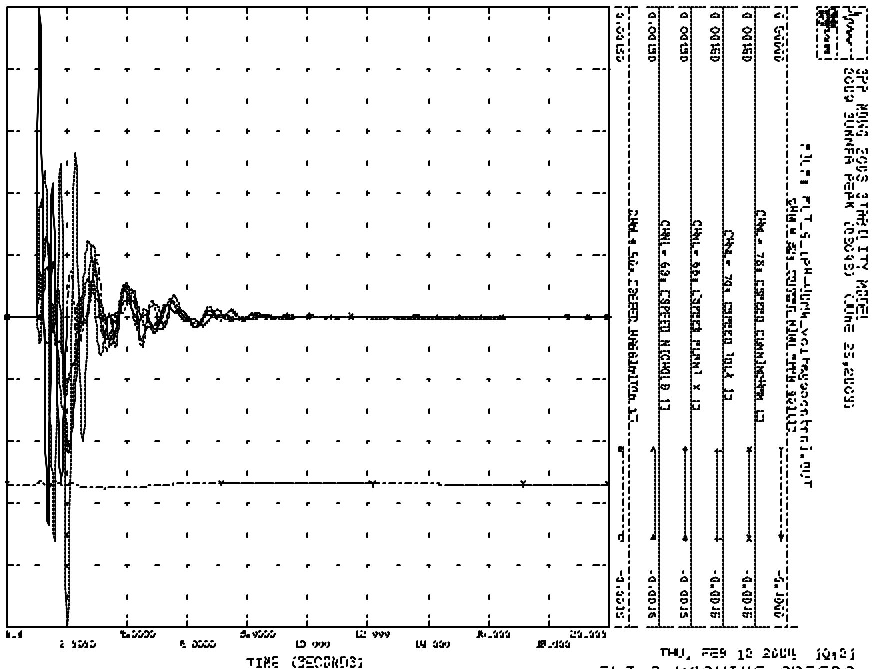
FLT_6 MACHINE SPEEDS



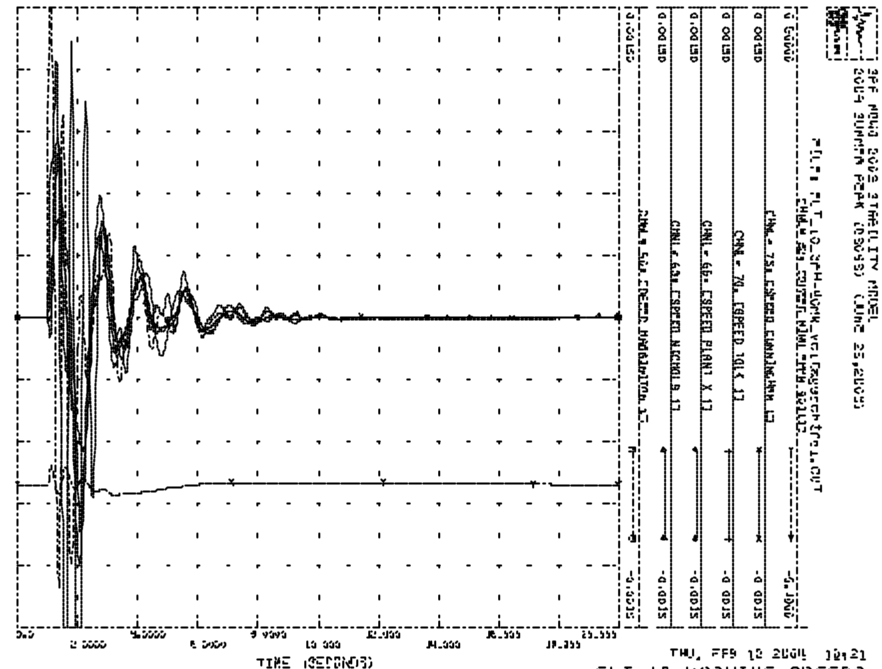
FLT_7 MACHINE SPEEDS



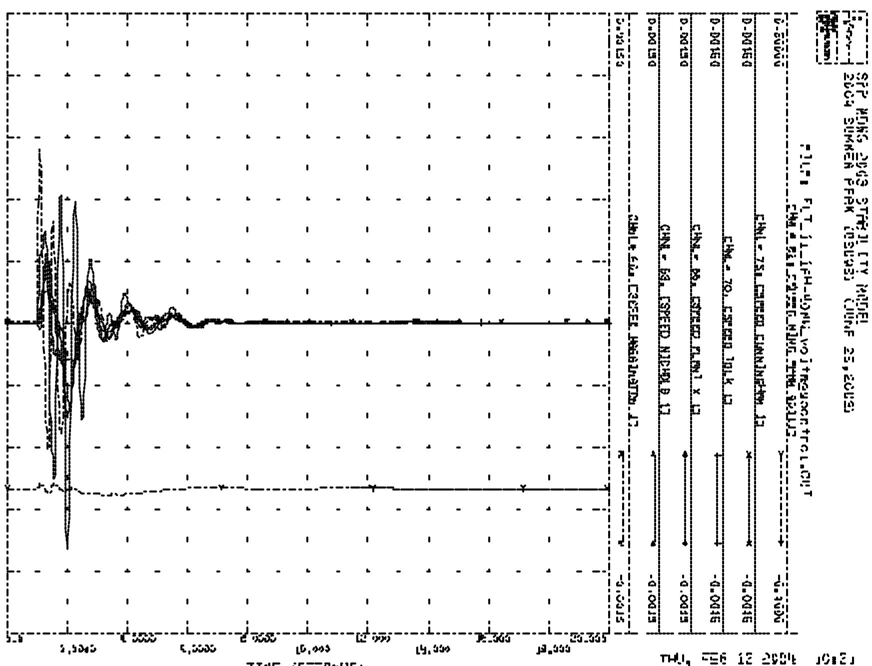
FLT_8 MACHINE SPEEDS



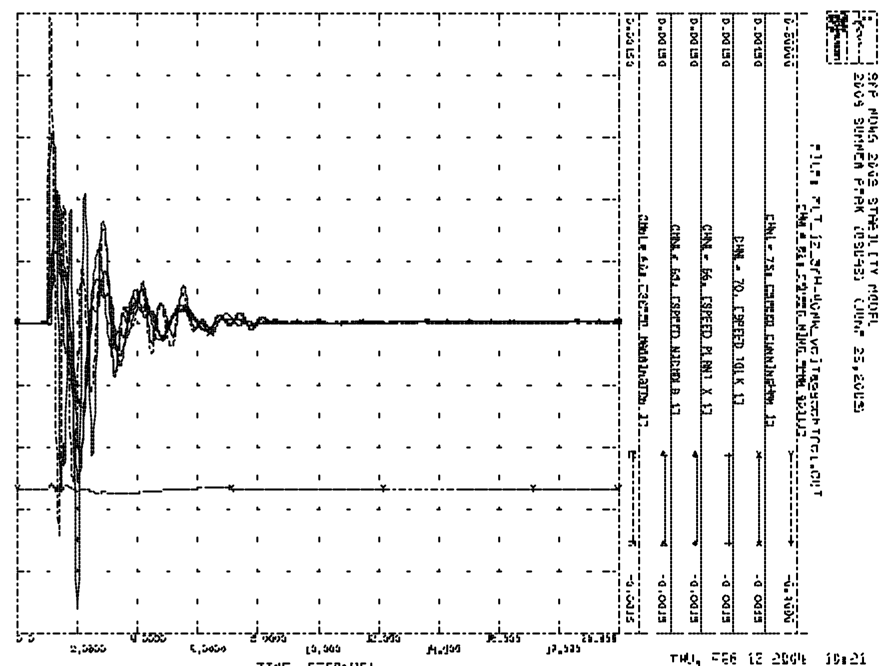
FLT_9 MACHINE SPEEDS



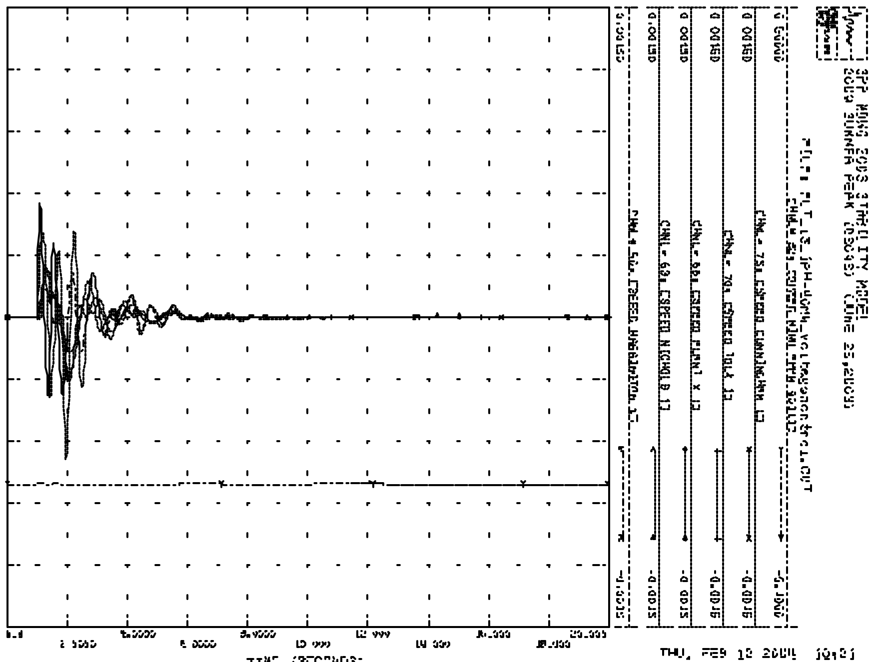
FLT_10 MACHINE SPEEDS



FLT_11 MACHINE SPEEDS



FLT_12 MACHINE SPEEDS



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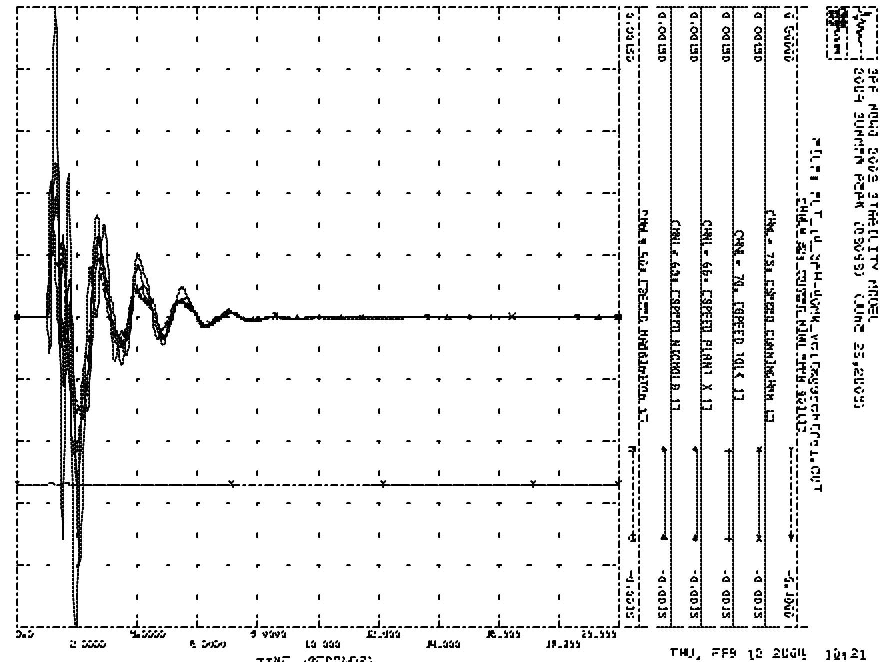
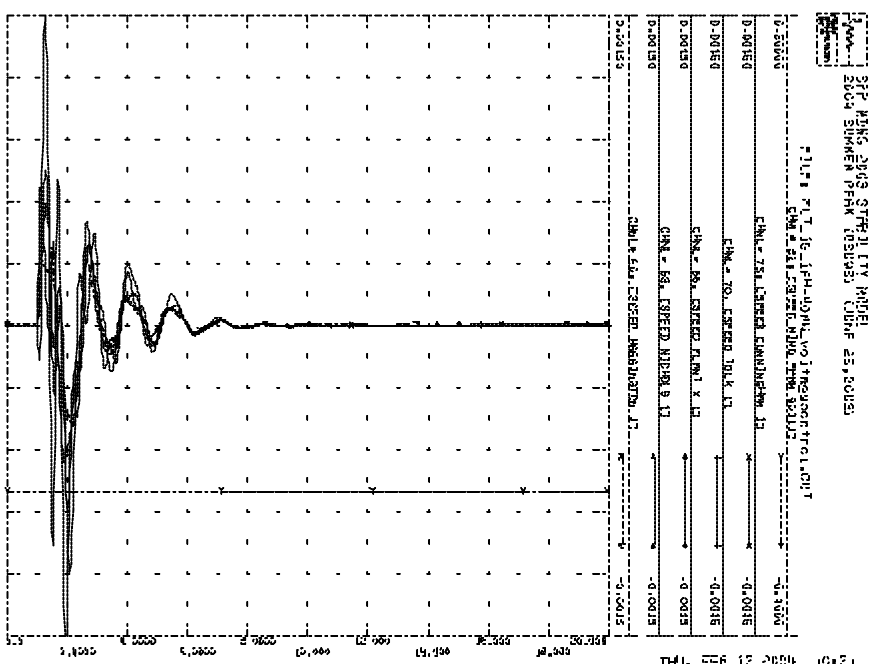


FLT_14 MACHINE SPEEDS



FLT_15 MACHINE SPEEDS

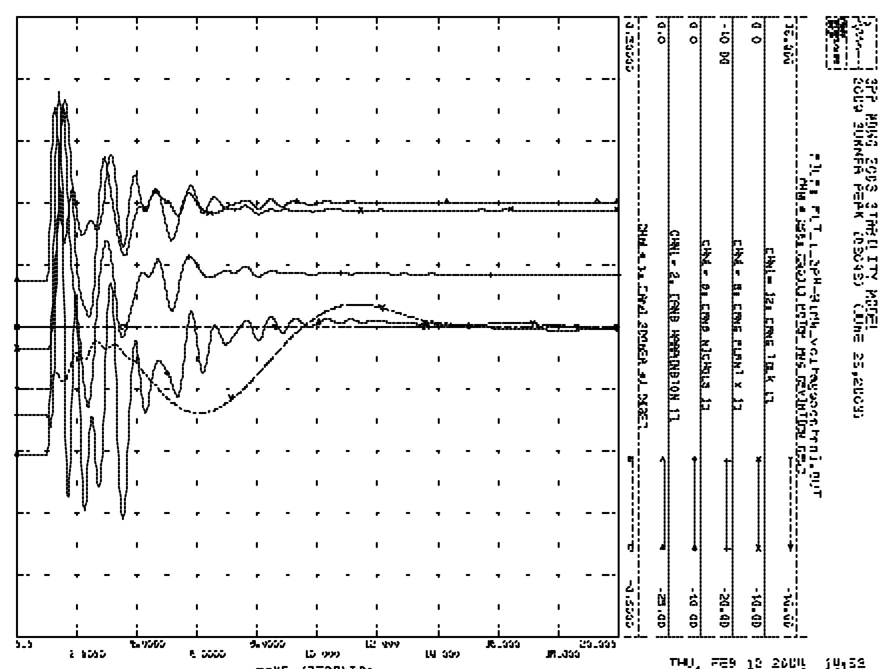
Appendix D

Plots of Fault Simulations

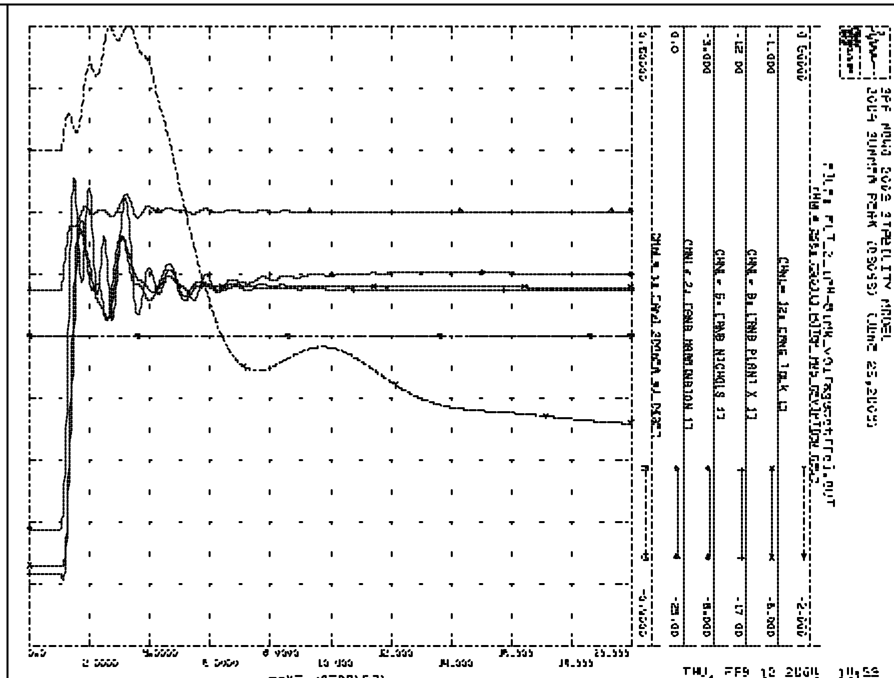
Section 1

Plots of Wind Farm generator equivalent #1 angle deviations during faults overlayed
With other SPS generator speeds
(All generator angle deviations are relative to OKGE Sooner #1)

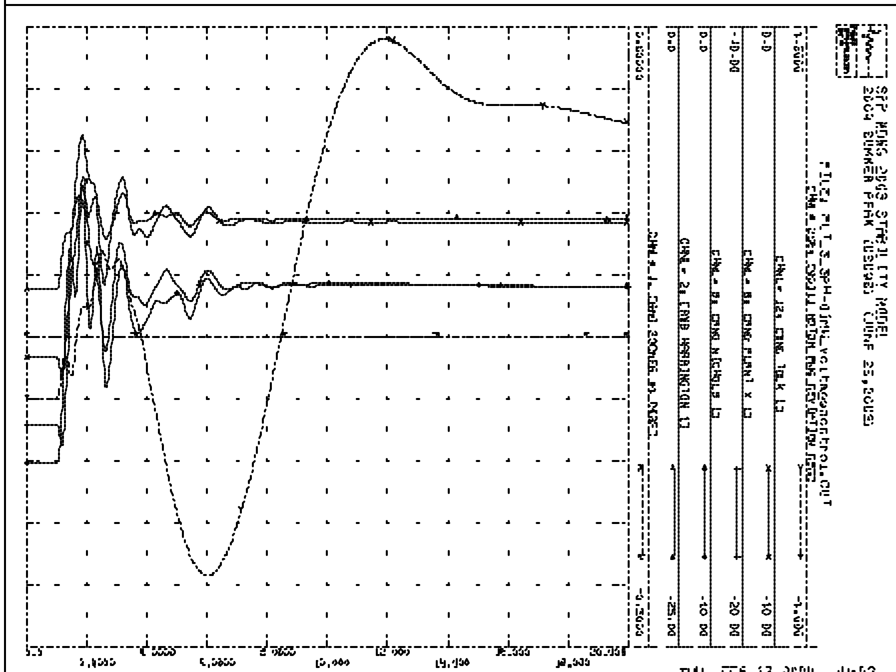
Scenario: Wind Farm at 81MW output and Voltage Control enabled



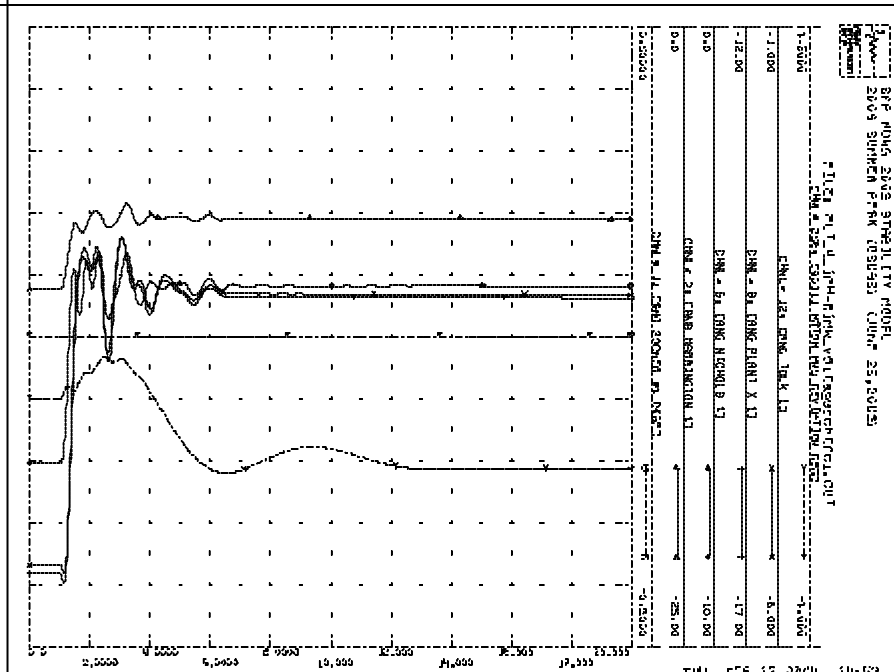
FLT_1 MACHINE ANGLES



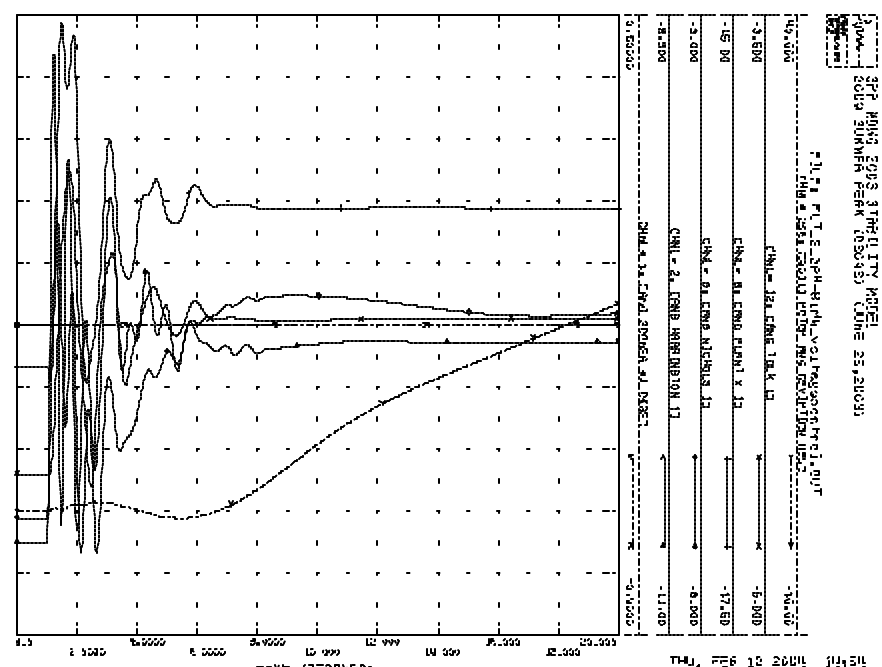
FLT_2 MACHINE ANGLES



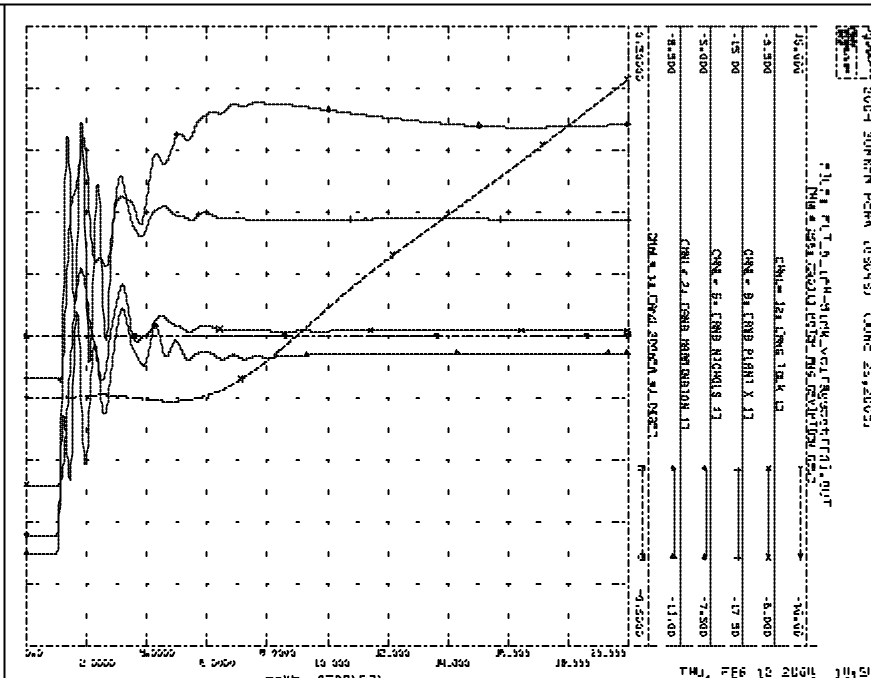
FLT_3 MACHINE ANGLES



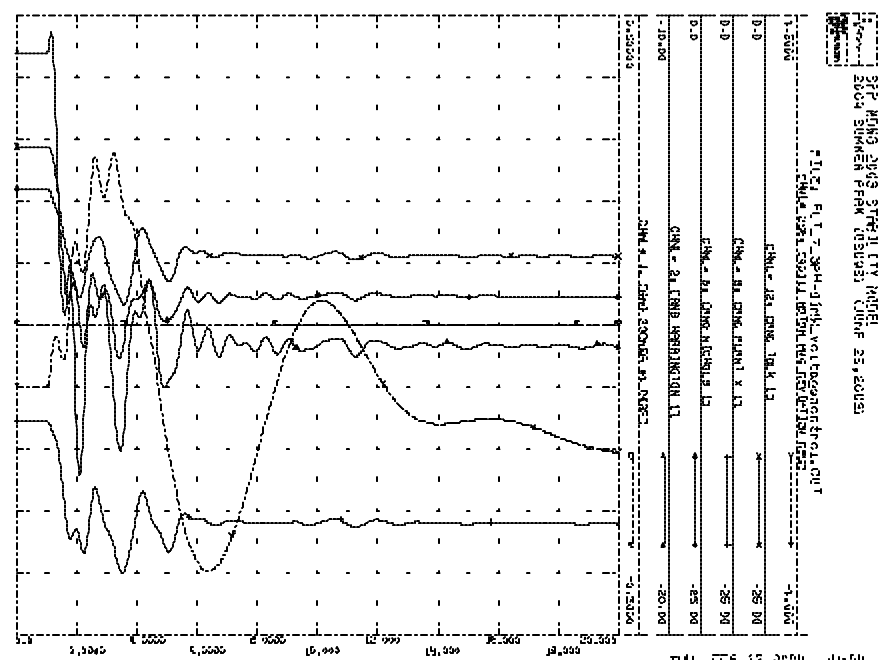
FLT_4 MACHINE ANGLES



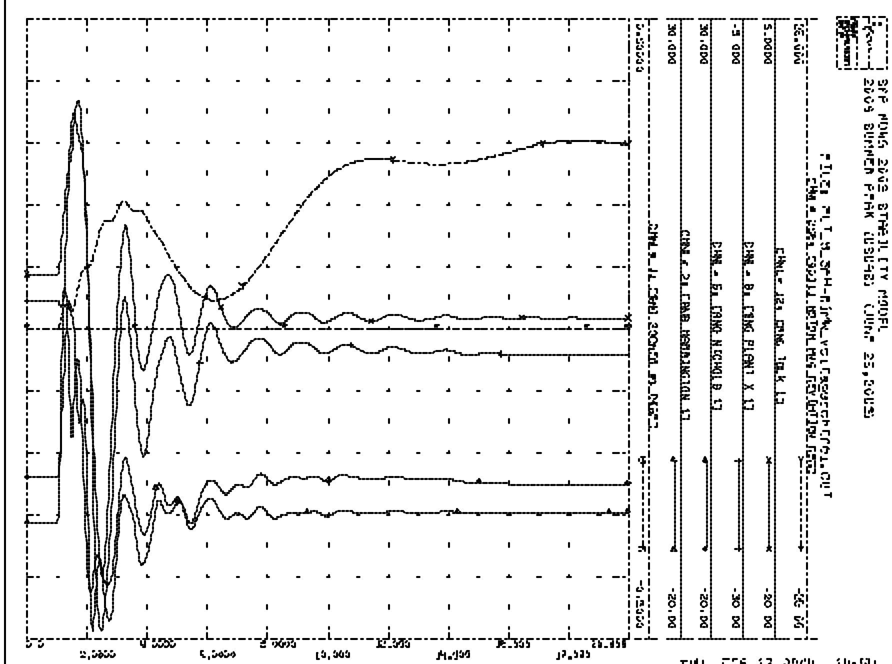
FLT_5 MACHINE ANGLES



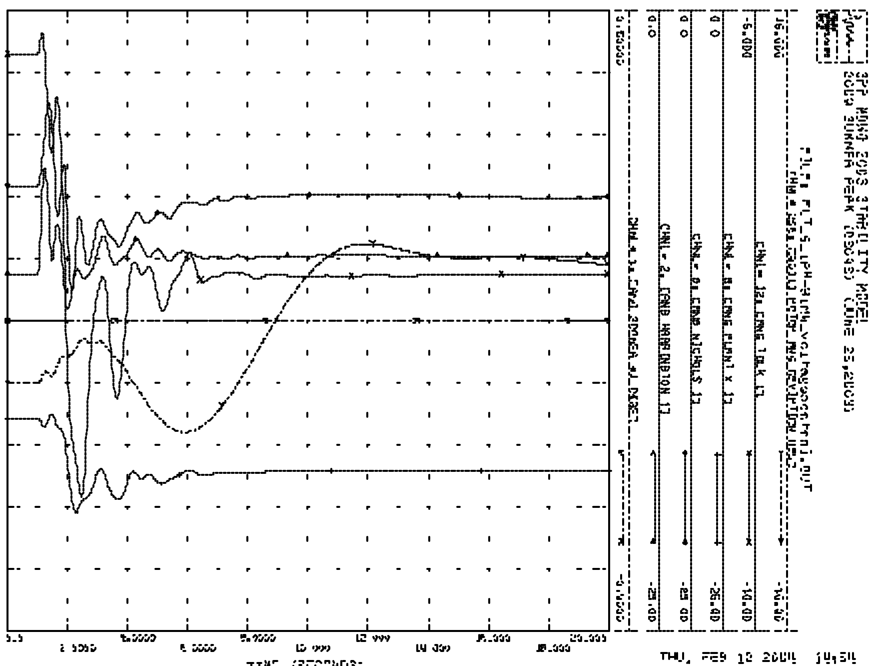
FLT_6 MACHINE ANGLES



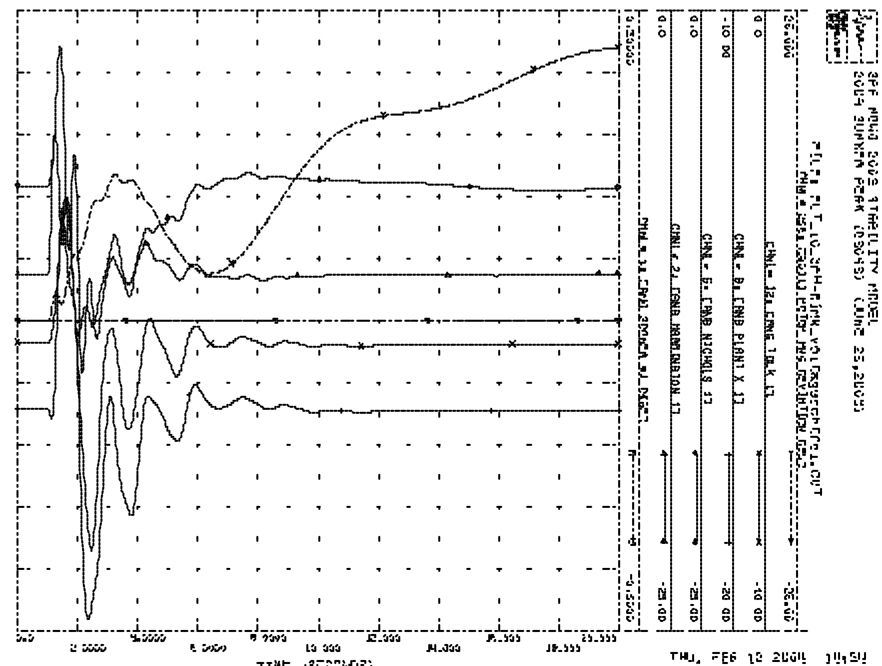
FLT_7 MACHINE ANGLES



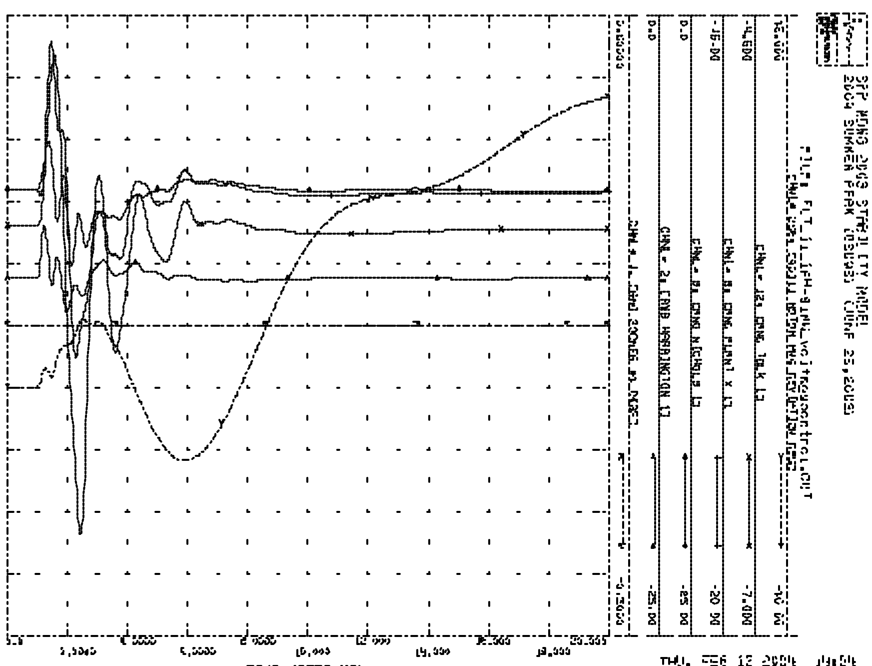
FLT_8 MACHINE ANGLES



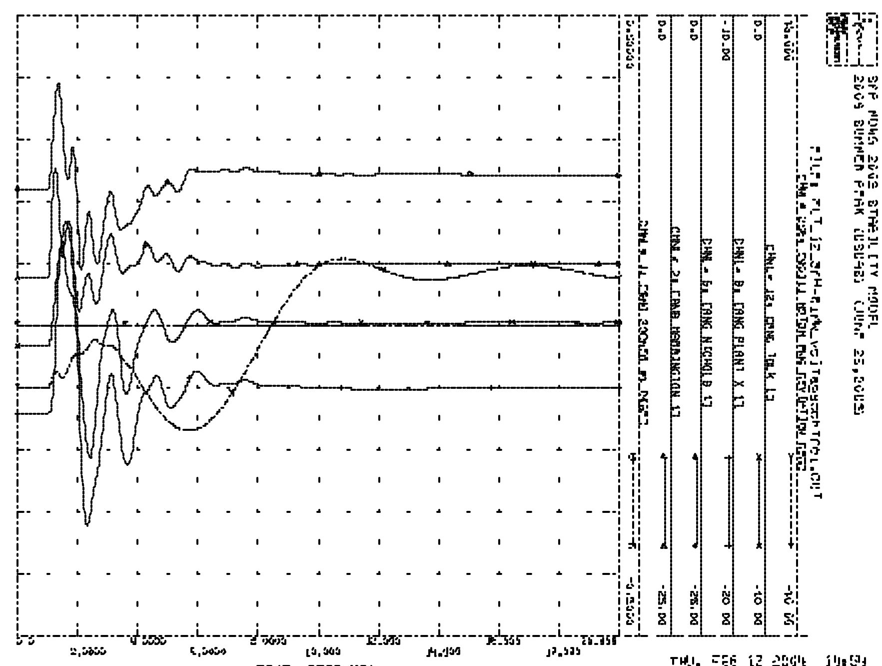
FLT_9 MACHINE ANGLES



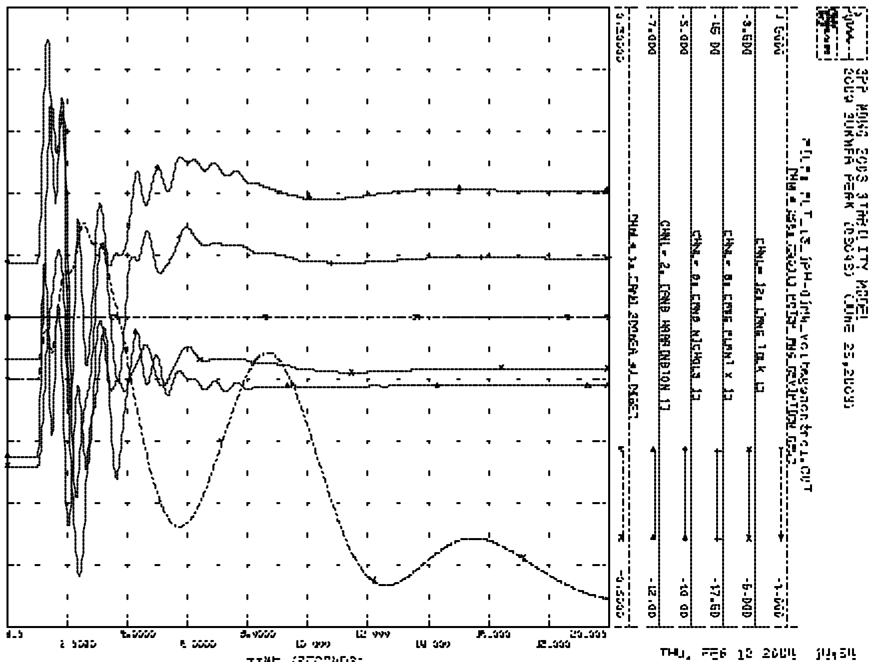
FLT_10 MACHINE ANGLES



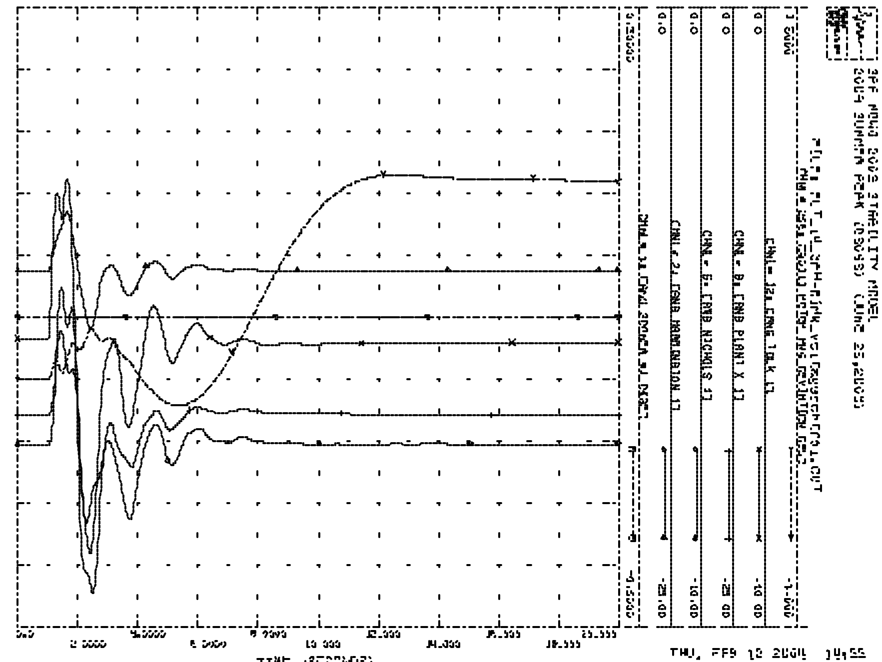
FLT_11 MACHINE ANGLES



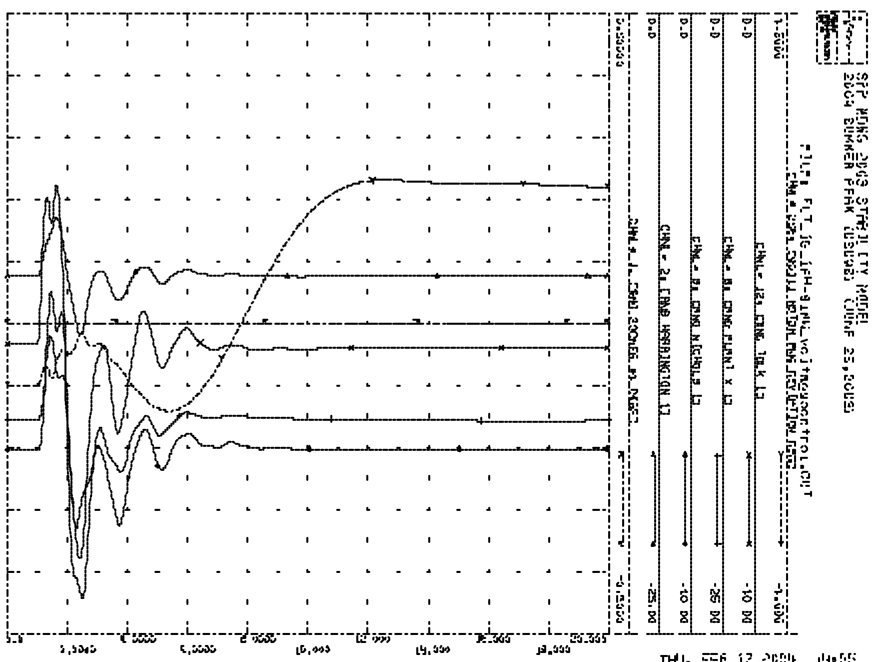
FLT_12 MACHINE ANGLES



FLT_13 MACHINE ANGLES



FLT_14 MACHINE ANGLES



FLT_15 MACHINE ANGLES

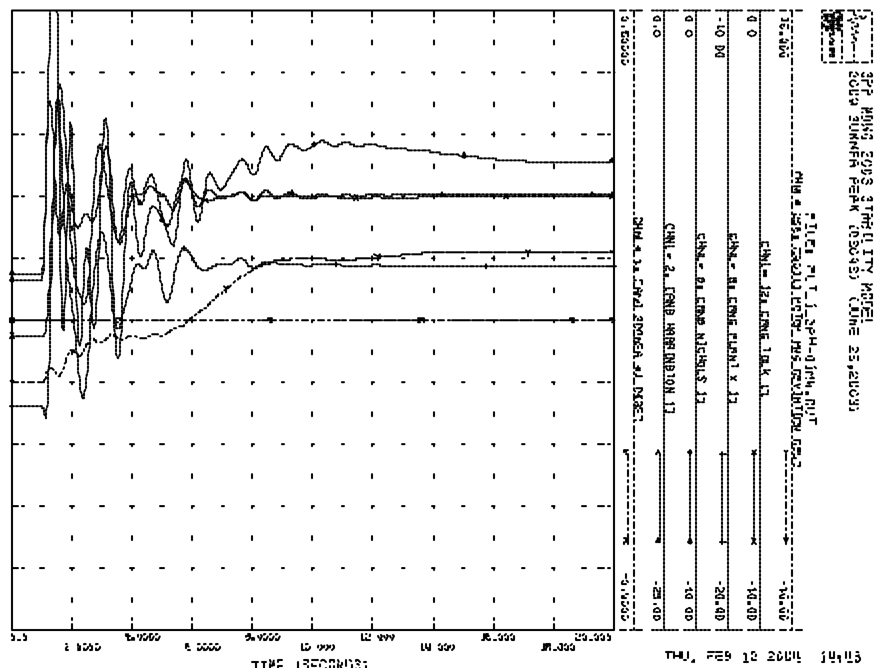
Appendix D

Plots of Fault Simulations

Section 2

Plots of Wind Farm generator equivalent #1 angle deviations during faults overlayed
With other SPS generator speeds
(All generator angle deviations are relative to OKGE Sooner #1)

Scenario: Wind Farm at 81MW output and Power Factor Control enabled



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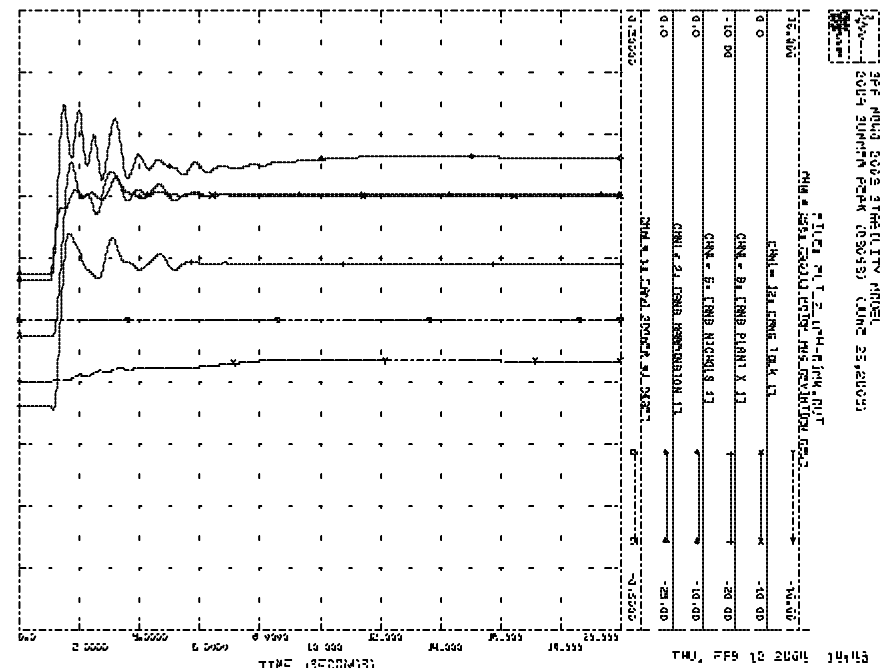
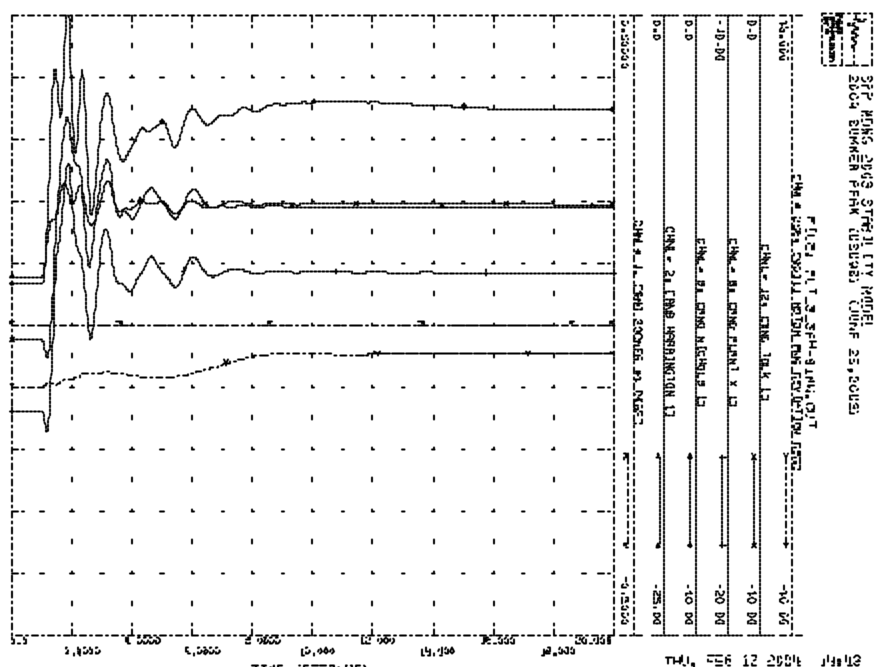
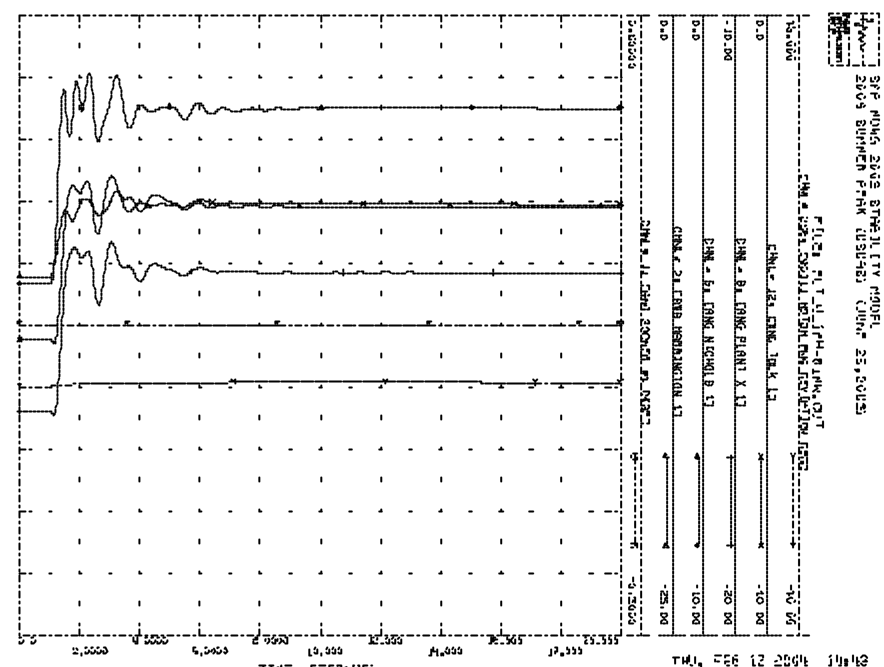


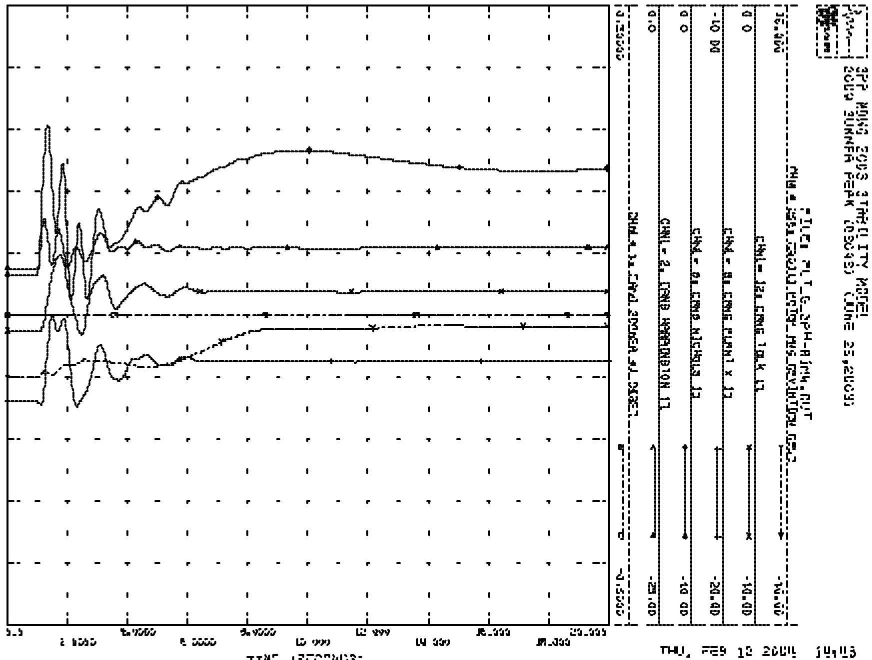
FLT_2 MACHINE ANGLES



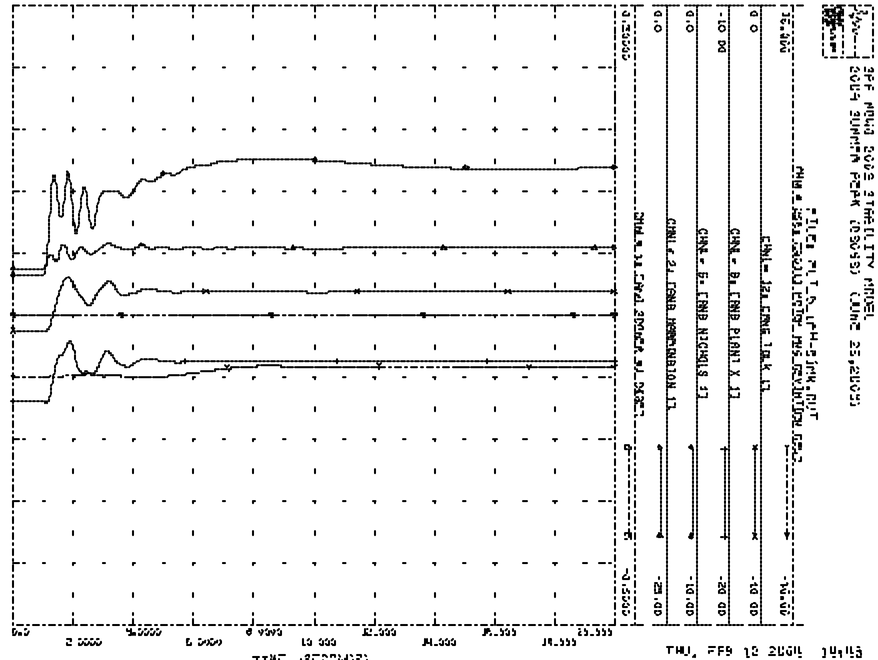
FLT_3 MACHINE ANGLES



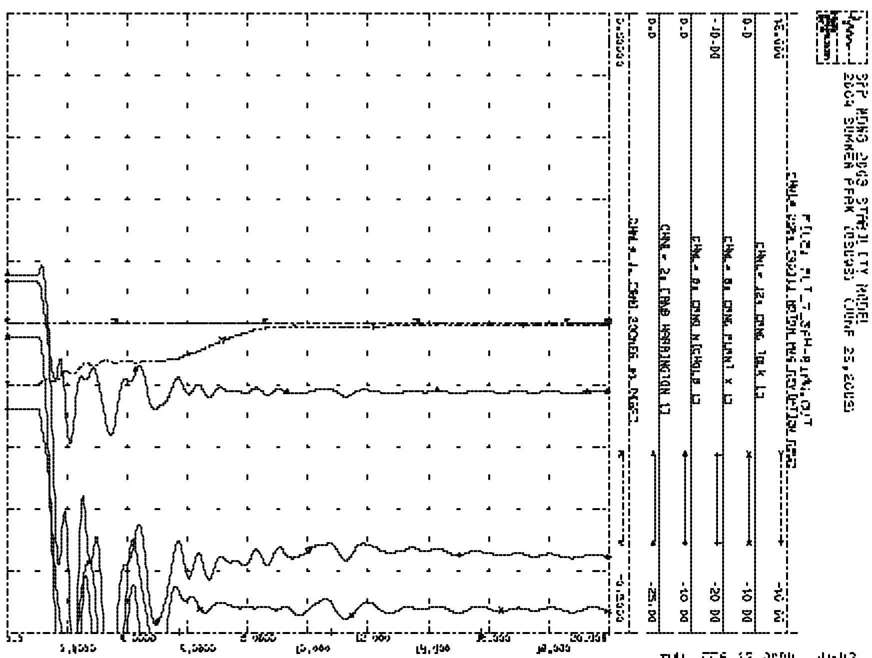
FLT_4 MACHINE ANGLES



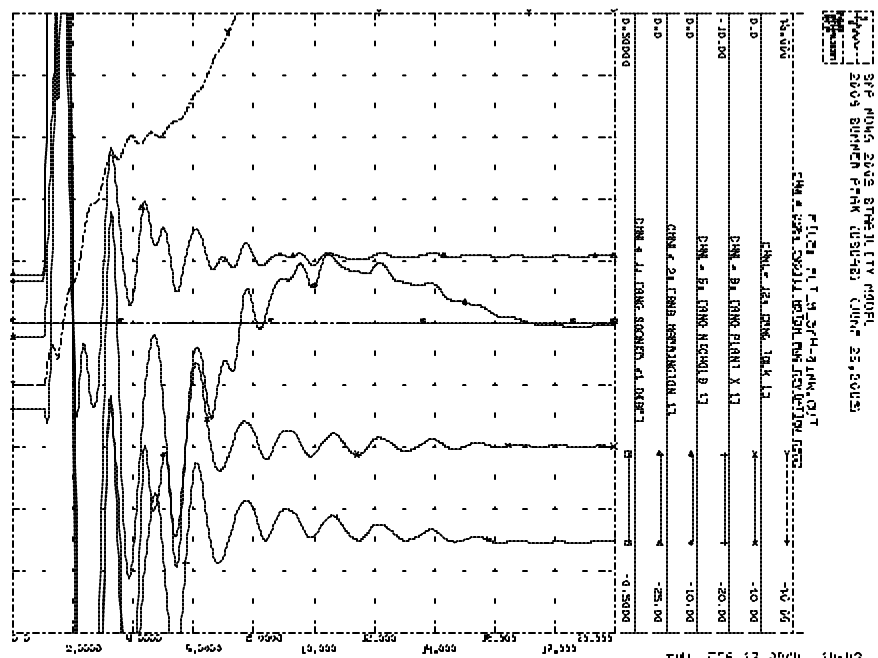
FLT_5 MACHINE ANGLES



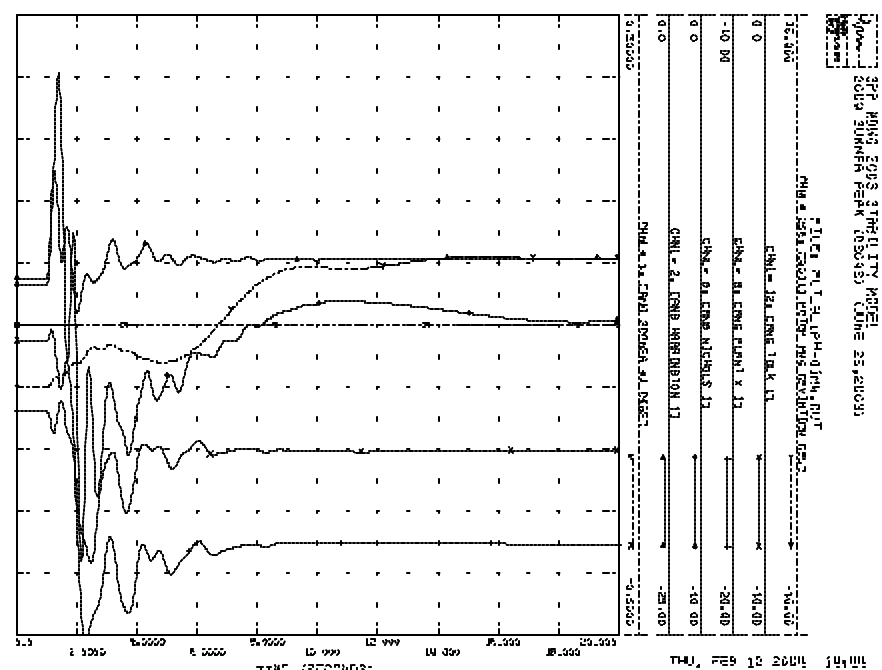
FLT_6 MACHINE ANGLES



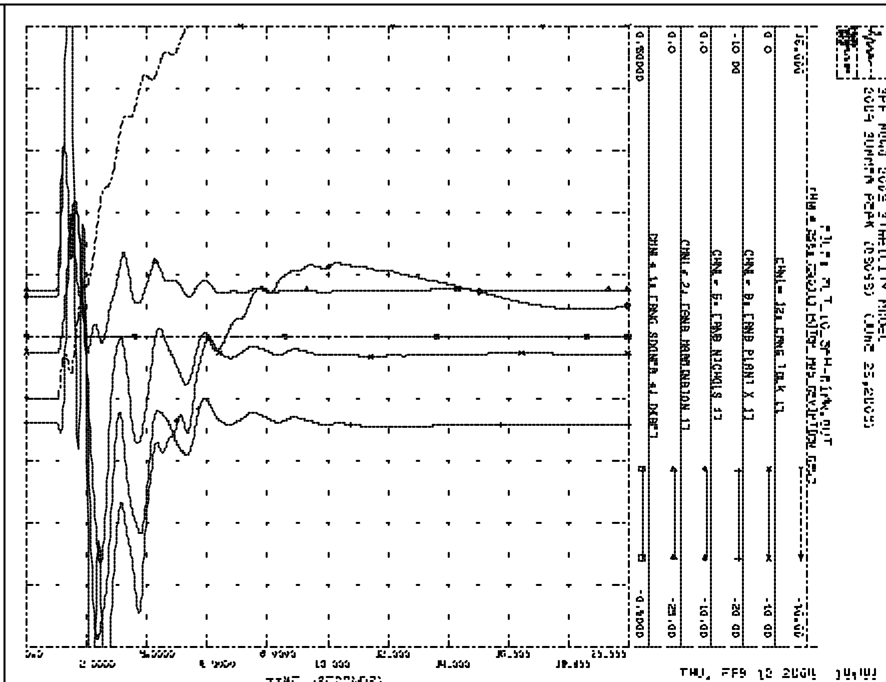
FLT_7 MACHINE ANGLES



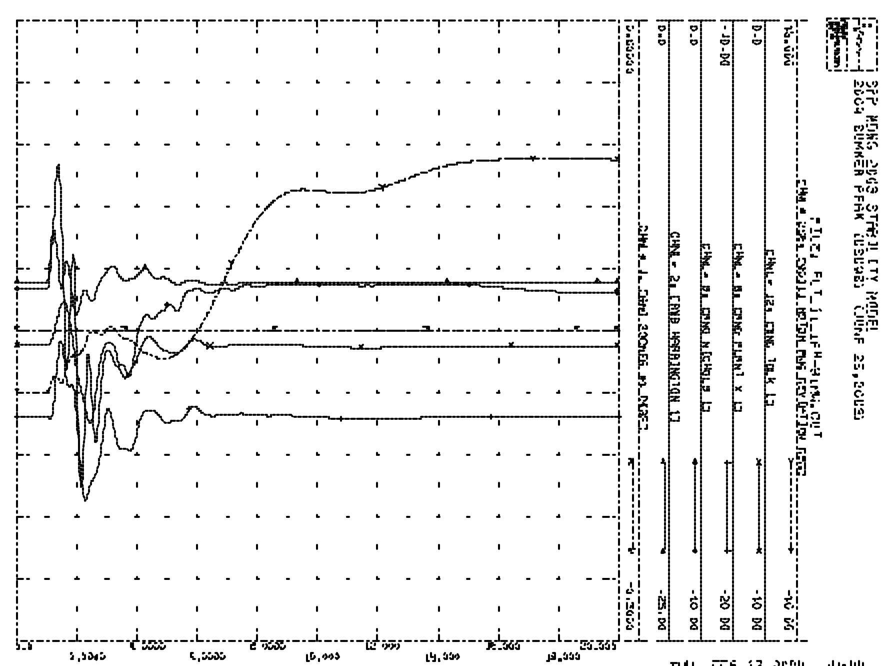
FLT_8 MACHINE ANGLES



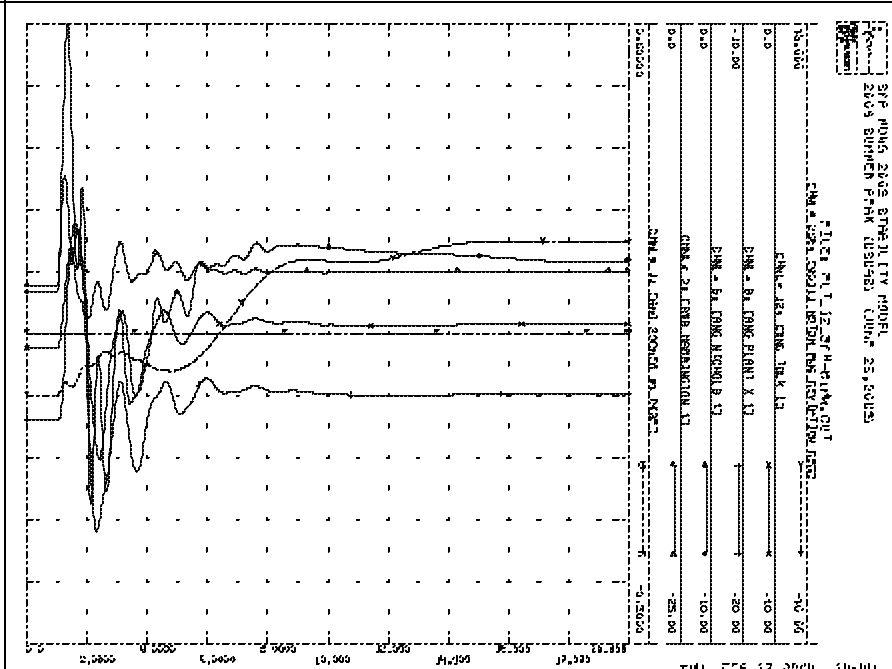
FLT_9 MACHINE ANGLES



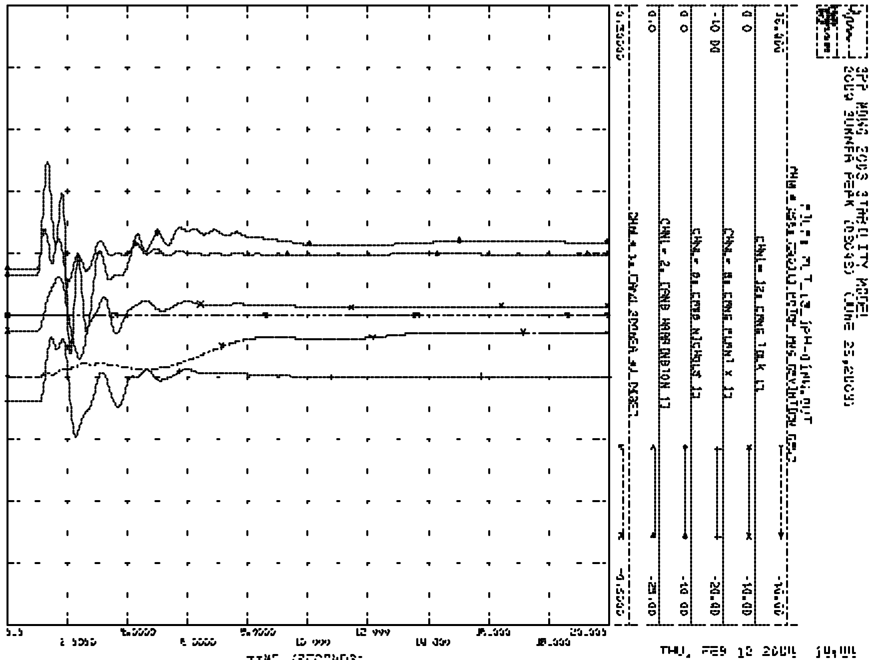
FLT_10 MACHINE ANGLES



FLT_11 MACHINE ANGLES



FLT_12 MACHINE ANGLES



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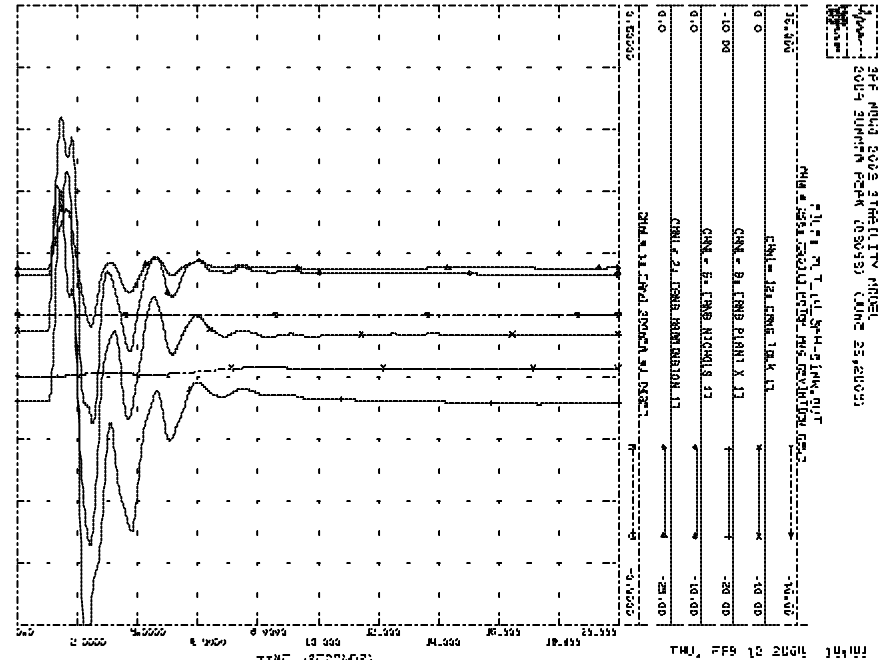
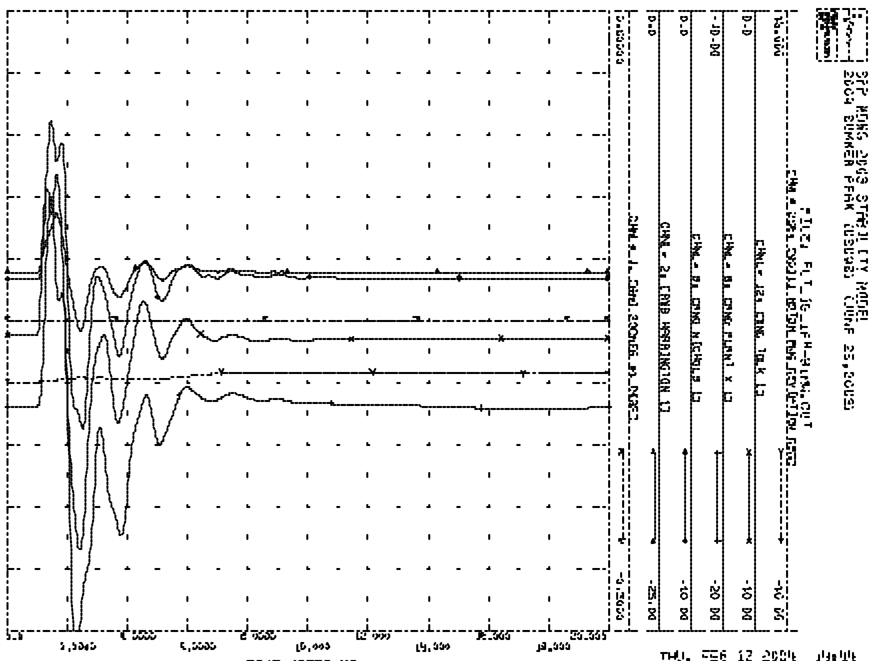


FLT_14 MACHINE ANGLES



FLT_15 MACHINE ANGLES

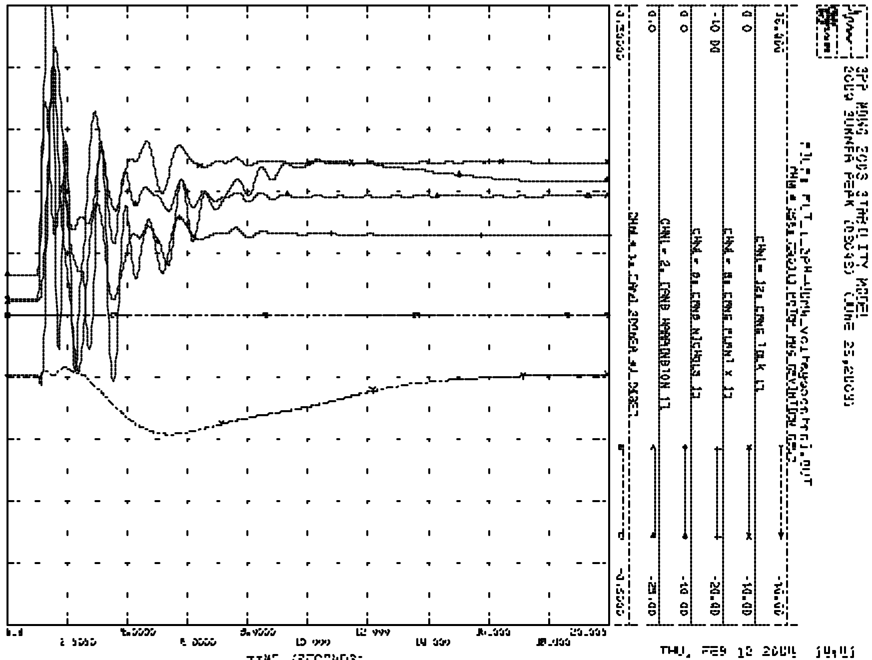
Appendix D

Plots of Fault Simulations

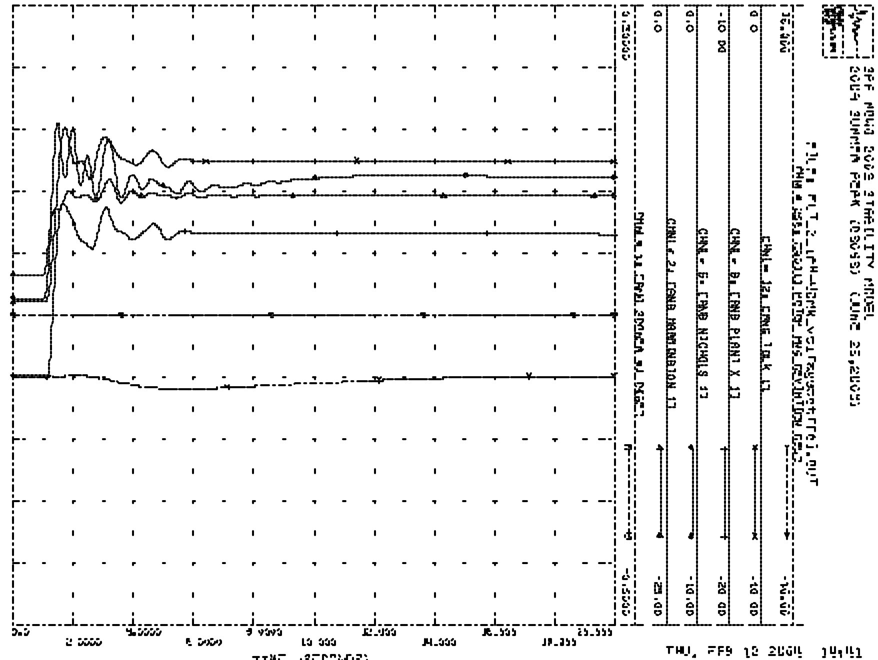
Section 3

Plots of Wind Farm generator equivalent #1 angle deviations during faults overlayed
With other SPS generator speeds
(All generator angle deviations are relative to OKGE Sooner #1)

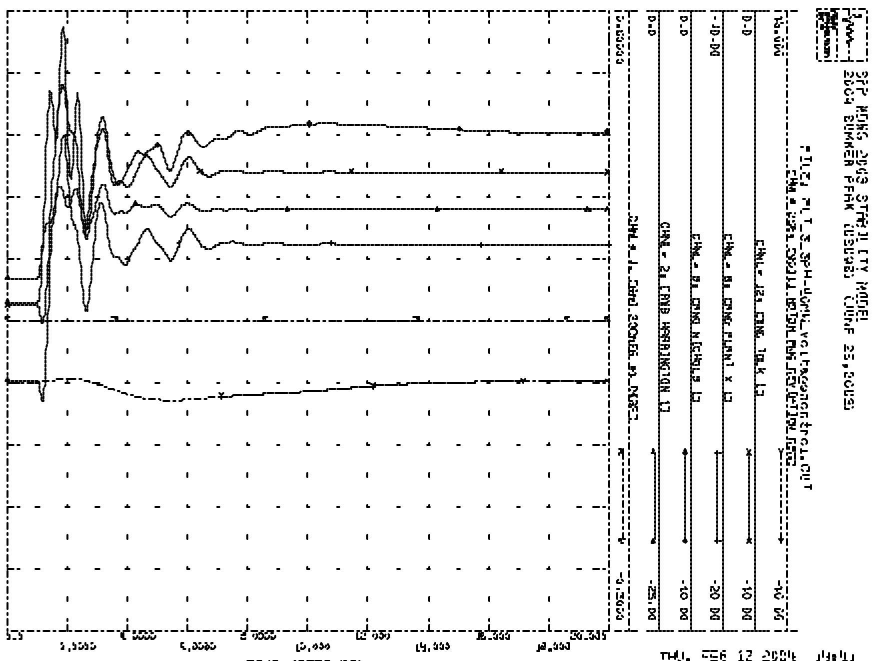
Scenario: Wind Farm at 40.5MW output and Voltage Control enabled



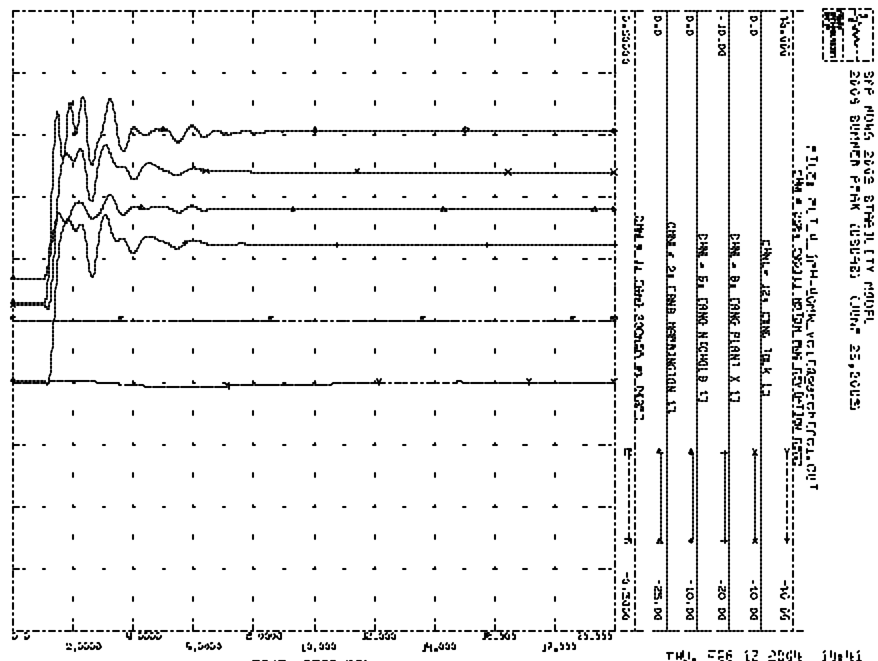
FLT_1 MACHINE ANGLES



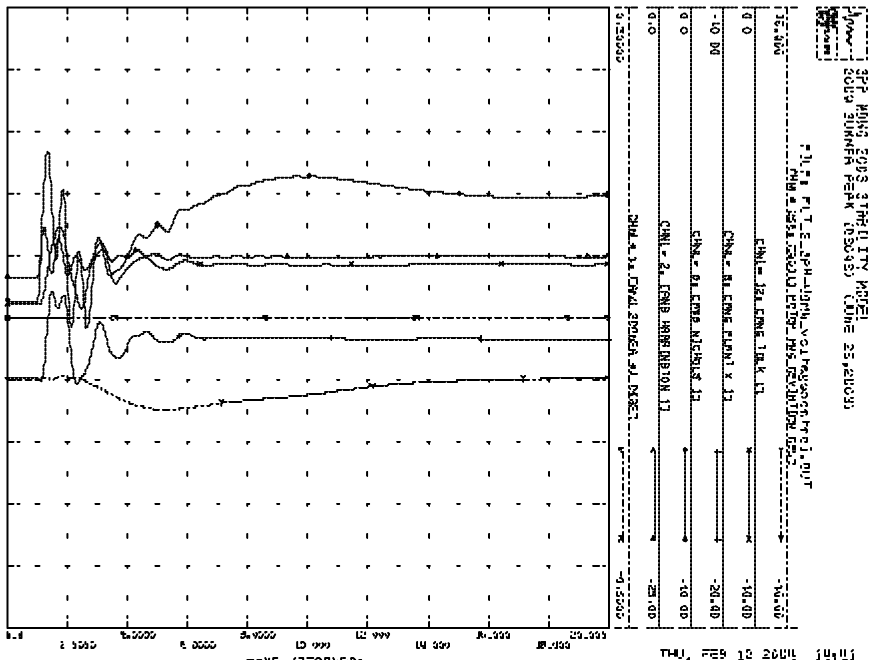
FLT_2 MACHINE ANGLES



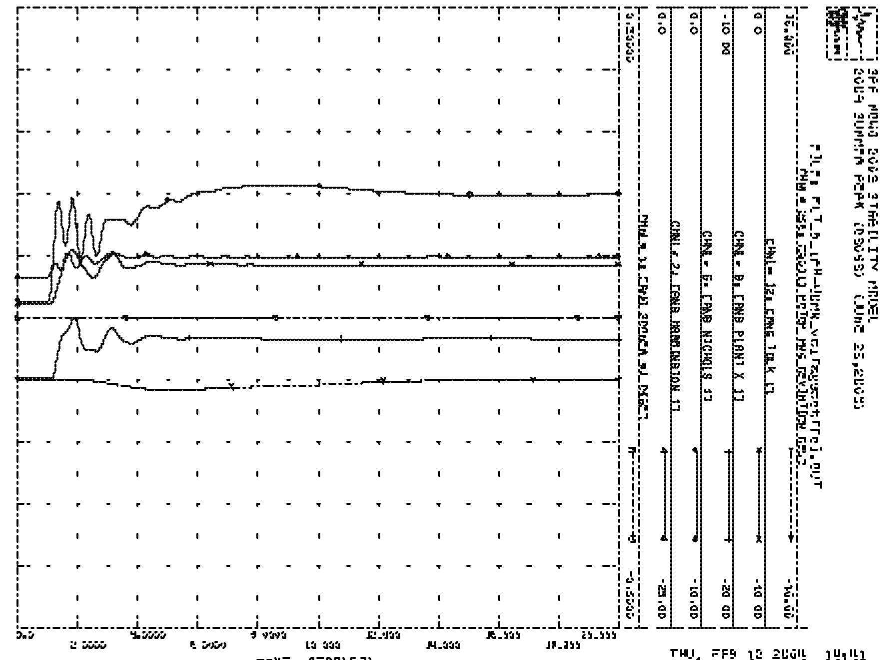
FLT_3 MACHINE ANGLES



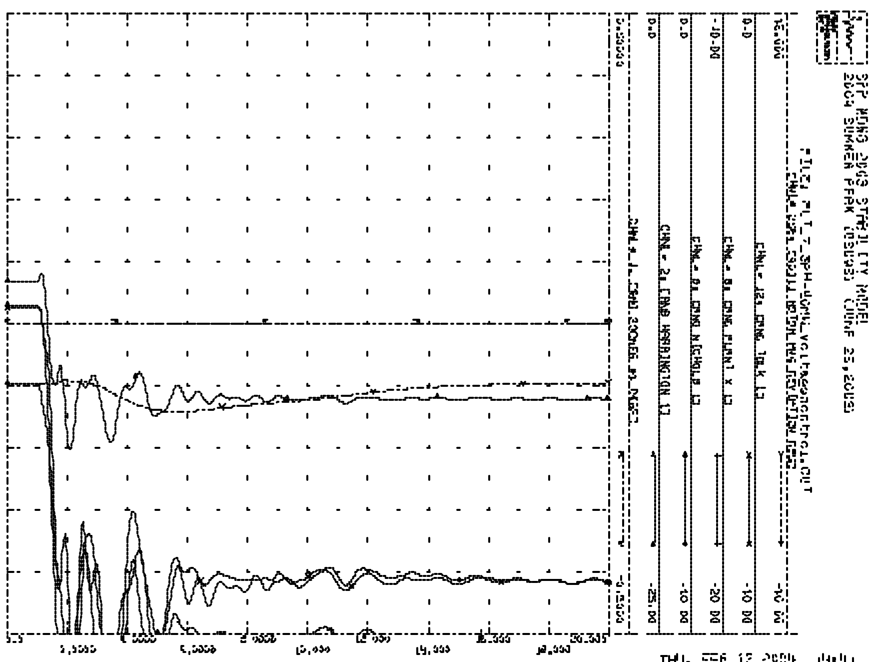
FLT_4 MACHINE ANGLES



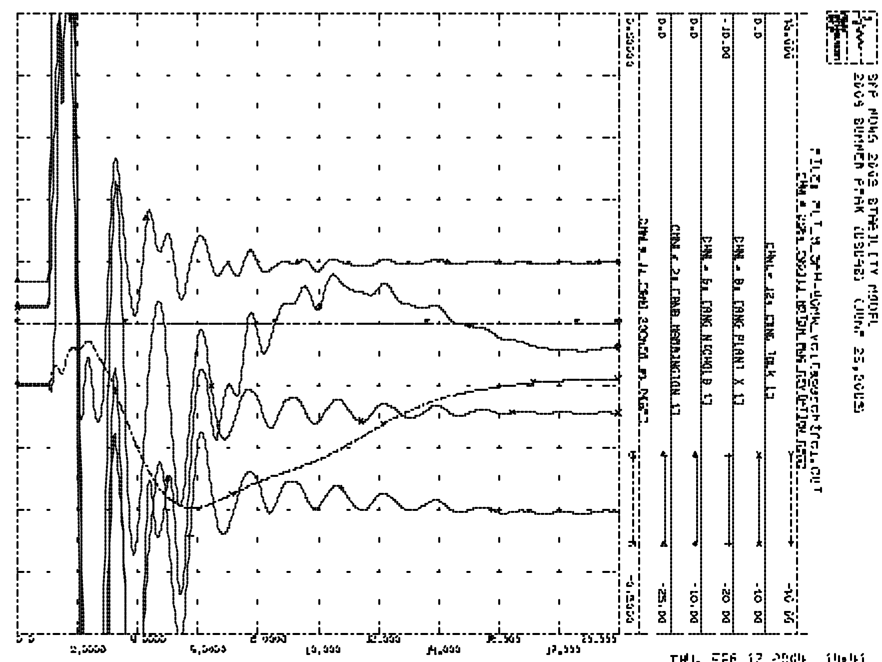
FLT_5 MACHINE ANGLES



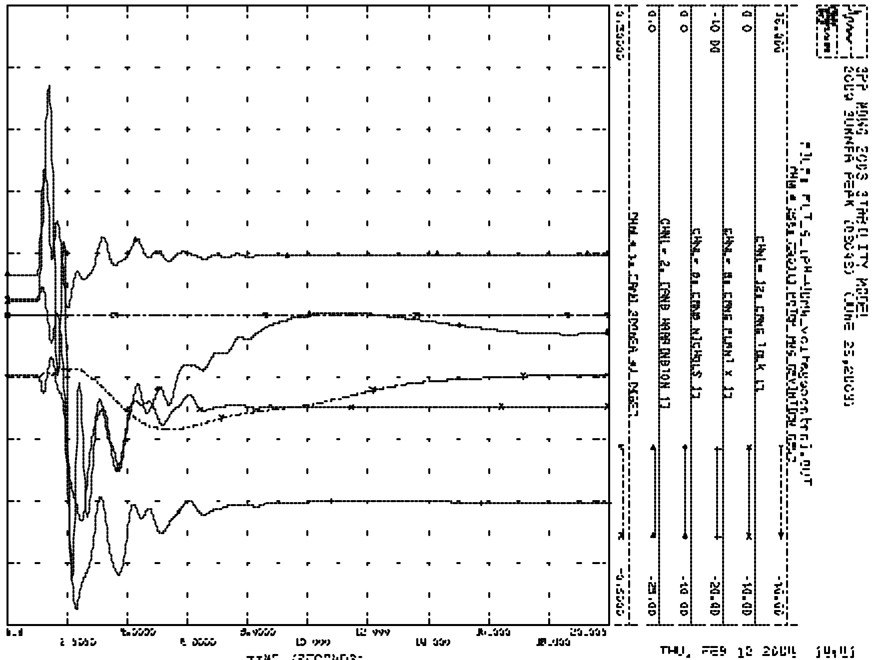
FLT_6 MACHINE ANGLES



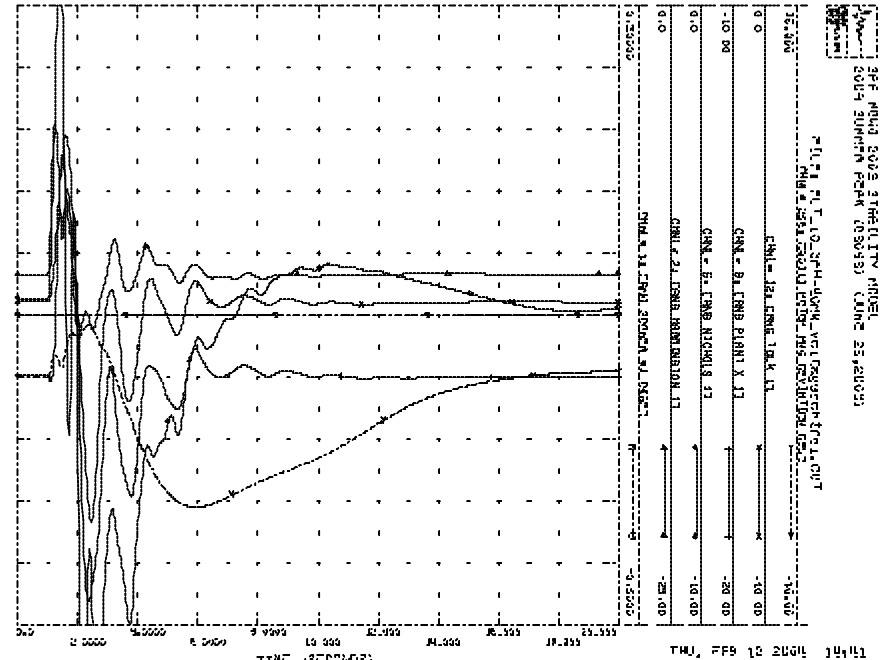
FLT_7 MACHINE ANGLES



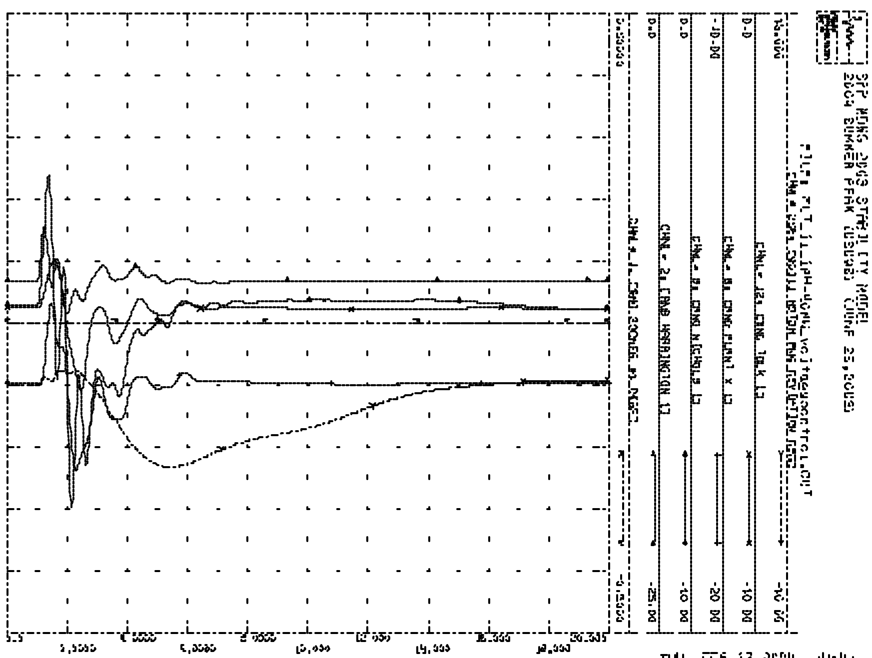
FLT_8 MACHINE ANGLES



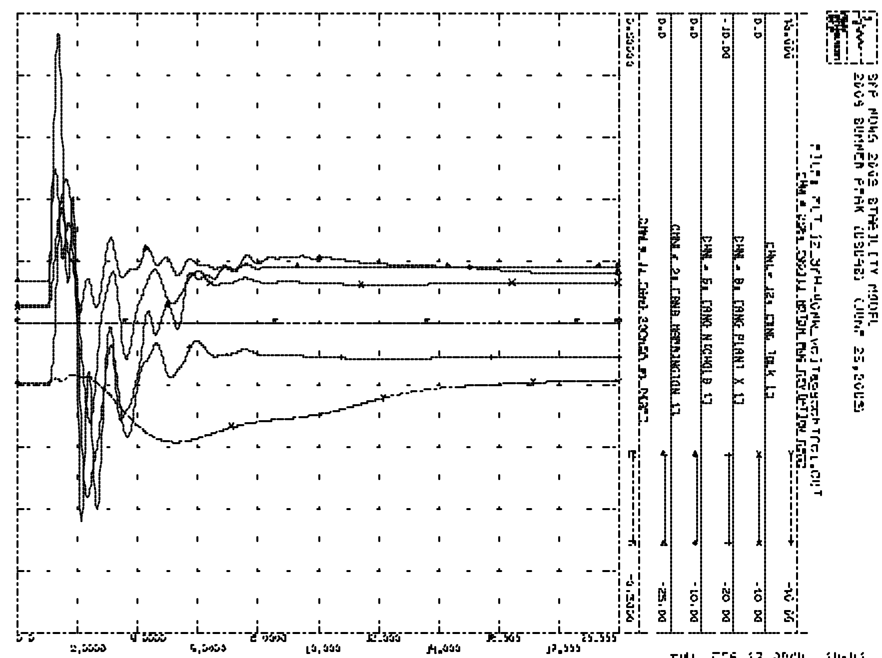
FLT_9 MACHINE ANGLES



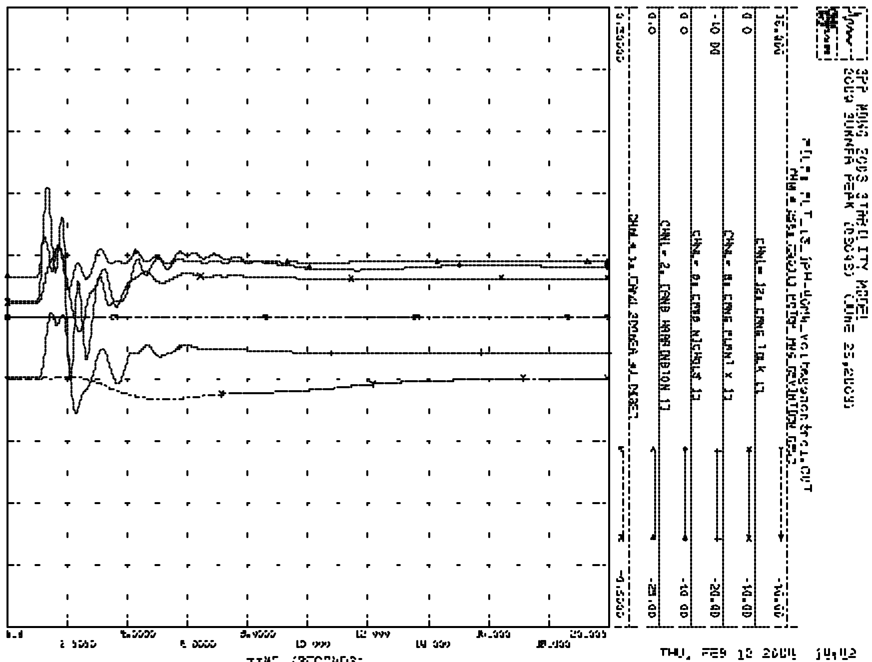
FLT_10 MACHINE ANGLES



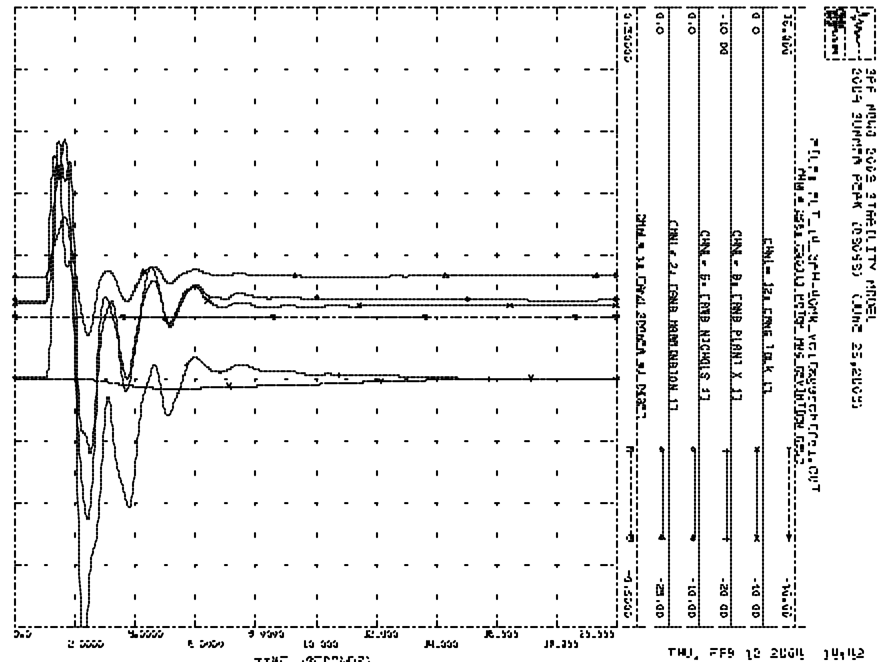
FLT_11 MACHINE ANGLES



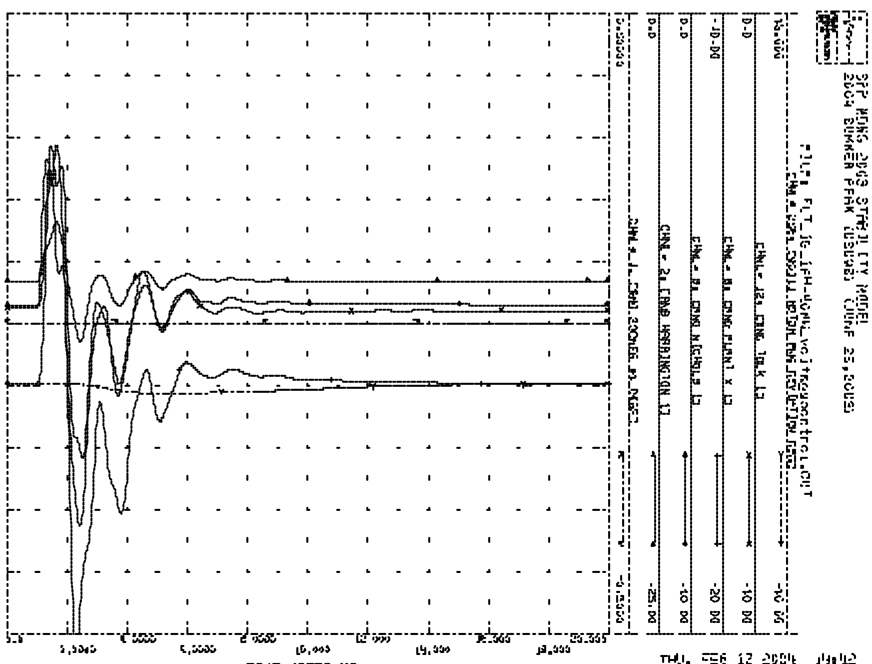
FLT_12 MACHINE ANGLES



FLT_13 MACHINE ANGLES



FLT_14 MACHINE ANGLES



FLT_15 MACHINE ANGLES