Generation Interconnection
Revision 2
System Impact Study Report

For

PJM Generation Interconnection Request Queue Position AD2-022/AD2-023

East Danville (AEP) – Roxborough (DEP) 230 kV

July 2022

Preface

The intent of the System Impact Study is to determine a plan, with approximate cost and construction time estimates, to connect the subject generation interconnection project to the PJM network at a location specified by the Interconnection Customer. As a requirement for interconnection, the Interconnection Customer may be responsible for the cost of constructing: Network Upgrades, which are facility additions, or upgrades to existing facilities, that are needed to maintain the reliability of the PJM system. All facilities required for interconnection of a generation interconnection project must be designed to meet the technical specifications (on PJM web site) for the appropriate transmission owner.

In some instances, a generator interconnection may not be responsible for 100% of the identified network upgrade cost because other transmission network uses, e.g. another generation interconnection, may also contribute to the need for the same network reinforcement. Cost allocation rules for network upgrades can be found in PJM Manual 14A, Attachment B. The possibility of sharing the reinforcement costs with other projects may be identified in the feasibility study, but the actual allocation will be deferred until the impact study is performed.

The System Impact Study estimates do not include the feasibility, cost, or time required to obtain property rights and permits for construction of the required facilities. The project developer is responsible for the right of way, real estate, and construction permit issues. For properties currently owned by Transmission Owners, the costs may be included in the study.

The Interconnection Customer seeking to interconnect a wind or solar generation facility shall maintain meteorological data facilities as well as provide that meteorological data which is required per Schedule H to the Interconnection Service Agreement and Section 8 of Manual 14D.

An Interconnection Customer with a proposed new Customer Facility that has a Maximum Facility Output equal to or greater than 100 MW shall install and maintain, at its expense, phasor measurement units (PMUs). See Section 8.5.3 of Appendix 2 to the Interconnection Service Agreement as well as section 4.3 of PJM Manual 14D for additional information.

General

Firefly Solar, LLC proposes to install PJM Project #AD2-022/AD2-023, a combined 150.0 MW (95.0 MW Capacity) solar facility in Pittsylvania County, Virginia (see Figure 2). The point of interconnection will be to the East Danville (AEP) – Roxborough (DEP) 230 kV circuit in the AEP area (see Figure 1).

The requested in service date is June 1, 2020.

Attachment Facilities

Point of Interconnection (East Danville - Roxborough 230 kV)

To accommodate the interconnection on the East Danville - Roxborough 230 kV circuit, a new three (3) circuit breaker 230 kV switching station physically configured in a breaker and half bus arrangement but operated as a ring-bus will be constructed (see Figure 1). Installation of associated protection and control equipment, 230 kV line risers, SCADA, and 230 kV revenue metering will also be required. AEP reserves the right to specify the final acceptable configuration considering design practices, future expansion, and compliance requirements.

New Switching Station Work and Cost:

- Construct a new three (3) circuit breaker 230 kV switching station physically configured in a breaker and half bus arrangement but operated as a ring-bus (See Figure 1). Installation of associated protection and control equipment, 230 kV line risers and SCADA will also be required.
    - **Estimated Station Cost: $7,000,000**

Direct Connection Cost Estimate

The total preliminary cost estimate for Direct Connection work is given in the following tables below.

For AEP building Direct Connection cost estimates:

Description	Estimated Cost
East Danville - Roxborough 230 kV T-Line Cut In	$1,000,000
Total	**$1,000,000**

Table 1

Non-Direct Connection Cost Estimate

The total preliminary cost estimate for Non-Direct Connection work is given in the following table below:

For AEP building Non-Direct Connection cost estimates:

Description	Estimated Cost
230 kV Revenue Metering	$300,000
Upgrade line protection and controls at the East Danville 230 kV substation.	$300,000
Generator lead first span exiting the POI station, including the first structure outside the fence	$1,250,000
Upgrade line protection and controls at the Roxborough 230 kV substation	To be provided by DEP
Total	**$1,850,000**

Table 2

Interconnection Customer Requirements

It is understood that Firefly Solar is responsible for all costs associated with this interconnection. The costs above are reimbursable to AEP. The cost of Firefly Solar's generating plant and the costs for the line connecting the generating plant to the East Danville - Roxborough 230 kV line are not included in this report; these are assumed to be the Firefly Solar's responsibility.

The Generation Interconnection Agreement does not in or by itself establish a requirement for American Electric Power to provide power for consumption at the developer's facilities. A separate agreement may be reached with the local utility that provides service in the area to ensure that infrastructure is in place to meet this demand and proper metering equipment is installed. It is the responsibility of the developer to contact the local service provider to determine if a local service agreement is required.

Requirement from the PJM Open Access Transmission Tariff:

1. An Interconnection Customer entering the New Services Queue on or after October 1, 2012 with a proposed new Customer Facility that has a Maximum Facility Output equal to or greater than 100 MW shall install and maintain, at its expense, phasor measurement units (PMUs). See Section 8.5.3 of Appendix 2 to the Interconnection Service Agreement as well as section 4.3 of PJM Manual 14D for additional information.

2. The Interconnection Customer may be required to install and/or pay for metering as necessary to properly track real time output of the facility as well as installing metering which shall be used for billing purposes. See Section 8 of Appendix 2 to the Interconnection Service Agreement as well as Section 4 of PJM Manual 14D for additional information.

Revenue Metering and SCADA Requirements

PJM Requirements

The Interconnection Customer will be required to install equipment necessary to provide Revenue Metering (KWH, KVARH) and real time data (KW, KVAR) for IC's generating Resource. See PJM Manuals M-01 and M-14D, and PJM Tariff Sections 24.1 and 24.2.

AEP Requirements

The Interconnection Customer will be required to comply with all AEP Revenue Metering Requirements for Generation Interconnection Customers. The Revenue Metering Requirements may be found within the "Requirements for Connection of New Facilities or Changes to Existing Facilities Connected to the AEP Transmission System" document located at the following link:

http://www.pjm.com/~/media/planning/plan-standards/private-aep/aep-interconnection-requirements.ashx

Network Impacts

The Queue Project AD2-023 (AD2-022 & AD2-023 combined) was evaluated as a 150.0 MW (Capacity 95.0 MW) injection into a tap of the East Danville – Roxborough 230 kV line in the AEP area. Project AD2-023 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AD2-023 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Summer Peak Analysis - 2021

Generator Deliverability

(Single or N-1 contingencies for the Capacity portion only of the interconnection)

None

Multiple Facility Contingency

(Double Circuit Tower Line, Fault with a Stuck Breaker, and Bus Fault contingencies for the full energy output)

AD2-022/AD2-023 Multiple Facility Contingency

#	Type	Contingency Name	Affected Area	Facility Description	Bus From	Bus To	Cir.	PF	Loading Initial	Loading Final	Rating Type	Rating MVA	MW Con.	FG App.
1	LFFB	AEP_P4_#11112_05J.FERR 765_A1	AEP - AEP	05EDAN 1-05DANVL2 138 kV line	242631	242620	1	AC	95.61	101.8	ER	415	26.47	1

Contribution to Previously Identified Overloads

(This project contributes to the following contingency overloads, i.e. "Network Impacts", identified for earlier generation or transmission interconnection projects in the PJM Queue)

None.

Affected System Analysis & Mitigation

LGEE Impacts:

None

MISO Impacts:

None

Duke, Progress & TVA Impacts:

None

OVEC Impacts:

None

Delivery of Energy Portion of Interconnection Request

PJM also studied the delivery of the energy portion of this interconnection request. Any problems identified below are likely to result in operational restrictions to the project under study. The developer can proceed with network upgrades to eliminate the operational restriction at their discretion by submitting a Merchant Transmission Interconnection request.
Only the most severely overloaded conditions are listed. There is no guarantee of full delivery of energy for this project by fixing only the conditions listed in this section. With a Transmission Interconnection Request, a subsequent analysis will be performed, which will study all overload conditions associated with the overloaded element(s) identified.

None.

Steady-State Voltage Requirements

(Summary of the VAR requirements based upon the results of the steady-state voltage studies)

No problems identified

Stability and Reactive Power Requirements for Low Voltage Ride Through

(Summary of the VAR requirements based upon the results of the dynamic studies)

Generator Interconnection Request AD2-022 is for a 96.0 MW Maximum Facility Output (MFO) solar generating facility. AD2-022 consists of 43 x SMA Sunny Central 2500-US inverters rated at 2.237 MW each. The Point of Interconnection (POI) is at a tap on East Danville – Roxboro 230 kV transmission line in the American Electric Power (AEP) transmission system, Pittsylvania County, Virginia. Generator Interconnection Request AD2-023 is for a 54.0 MW Maximum Facility Output (MFO) solar generating facility. AD2-023 consists of 25 x SMA Sunny Central 2500-US inverters rated at 2.237 MW each. The project connects to the low side (34.5 kV) of the substation for the Firefly Solar 96 MW project (AD2-022) in the American Electric Power (AEP) transmission system, Pittsylvania County, Virginia.

This report describes a dynamic simulation analysis of AD2-022 and AD2-023 as part of the overall system impact study.

The loadflow scenario for the analysis was based on the RTEP 2021 summer peak case, modified to include applicable queue projects. AD2-022 and AD2-023 have been dispatched online at maximum power output, with 1.0 p.u. voltage at the generator bus.

AD2-022 and AD2-023 were tested for compliance with NERC, PJM, Transmission Owner and other applicable criteria. Steady-state condition and 36 contingencies were studied, each with at least a 20 second simulation time period. Studied faults included:

a) Steady state operation;

b) Three phase faults with normal clearing time;

c) Single-phase faults with stuck breaker;

d) Single-phase faults placed at 80% of the line with delayed (Zone 2) clearing at line end remote from the fault due to primary communications/relay failure.

No bus, multiple-circuit tower and high-speed reclosing (HSR) contingencies were identified for this study.

For all simulations, the queue projects under study along with the rest of the PJM system were required to maintain synchronism and with all states returning to an acceptable new condition following the disturbance.

For contingencies P1.01 – P1.03 frequency relays tripped units AD2-022 and AD2-023 due to fictitious frequency spikes observed for the two units. The frequency relays at AD2-022 and AD2-023 were disabled for the above contingencies to resolve the tripping issues.

For all of the fault contingencies tested on the 2021 summer peak case:

a. AD2-022 and AD2-023 were able to ride through the faults (except for faults where protective action trips a generator(s)),
b. Post-contingency oscillations were positively damped with a damping margin of at least 3%.
c. Following fault clearing, all bus voltages recovered to a minimum of 0.7 per unit after 2.5 seconds (except where protective action isolates that bus).
d. No transmission element tripped, other than those either directly connected or designed to trip as a consequence of that fault.

The reactive power capability of both AD2-022 and AD2-023 meets the 0.95 lagging and leading PF requirement at the high side of the main transformer.

No mitigations were found to be required.

Short Circuit

(Summary of impacted circuit breakers)

New circuit breakers found to be over-duty:

None

Light Load Analysis

Light Load Studies (applicable to wind, coal, nuclear, and pumped storage projects).

Not required

New System Reinforcements

(Upgrades required to mitigate reliability criteria violations, i.e. Network Impacts, initially caused by the addition of this project generation)

Facility	Upgrade Description	Cost	Cost Allocation	Upgrade Number
05EDAN 1-05DANVL2 138 kV line (from bus 242631 to bus 242620 ckt 1)	**AEP** AEP SE rating is 415 MVA. AEP Reinforcement: **Project ID**: n6124	$7,500,000 + $500,000 + $300,000	$7,219,000 + $481,000 + $289,000	N6124 N7554.1 N7554.2

Increasing the Danville - East Danville 138 kV circuit summer rating to 337/482 MVA will still require us to rebuild the line. The network project has a projected in-service date of 09/01/2023.

The cost allocation is as follows:

Queue	MW contribution	Percentage of Cost	$ cost ($7.5 M)
AD1-152	1.03	3.75%	$0.281
AD2-023	26.47	96.25%	$7.219

AEP Reinforcement:
Project ID: n7554.1
Replace 5 Sub cond 2000 AAC 91 Str at Danville2 138kV station. Increase summer rating to 337/482.
Time Estimate: 12-18 months

The cost allocation is as follows:

Queue	MW contribution	Percentage of Cost	$ cost ($0.5 M)
AD1-152	1.03	3.75%	$0.019
AD2-023	26.47	96.25%	$0.481

AEP Reinforcement:
Project ID: n7554.2
Replace 3 Sub cond 2000 AAC 91 Str at East Danville 138kV station. Increase summer rating to 337/482.
Time Estimate: 12-18 months

The cost allocation is as follows:

Queue	MW contribution	Percentage of Cost	$ cost ($0.3 M)
AD1-152	1.03	3.75%	$0.011
AD2-023	26.47	96.25%	$0.289

	Total	**$8,300,000**	**$7,989,000**	

Contribution to Previously Identified System Reinforcements

(Overloads initially caused by prior Queue positions with additional contribution to overloading by this project. This project may have a % allocation cost responsibility which will be calculated and reported for the Impact Study)
(Summary form of Cost allocation for transmission lines and transformers will be inserted here if any)

None.

Contingency Descriptions

Contingency Name	Description
AEP_P4_#11112_05J.FERR 765_A1	CONTINGENCY 'AEP_P4_#11112_05J.FERR 765_A1' OPEN BRANCH FROM BUS 242511 TO BUS 242514 CKT 1 / 242511 05BROADF 765 242514 05J.FERR 765 1 OPEN BRANCH FROM BUS 242514 TO BUS 242520 CKT 1 / 242514 05J.FERR 765 242520 05J.FERR 500 1 OPEN BRANCH FROM BUS 242520 TO BUS 306719 CKT 1 / 242520 05J.FERR 500 306719 8ANTIOCH 500 1 OPEN BRANCH FROM BUS 242566 TO BUS 242567 CKT ZB / 242566 05BROADF 138 242567 05BROADX 138 ZB END

Schedule

It is anticipated that the time between receipt of executed agreements and Commercial Operation may range from 12 to 18 months if no line work is required. If line work is required, construction time would be between 24 to 36 months after signing an interconnection agreement.

Conclusion

Based upon the results of this System Impact Study, the construction of the 150.0 MW (95.0 MW Capacity) solar generating facility of Firefly Solar LLC (PJM Project #AD2-022/AD2-023) will require the following additional interconnection charges. This plan of service will interconnect the proposed solar generating facility in a manner that will provide operational reliability and flexibility to both the AEP system and the Firefly Solar generating facility.

Cost Breakdown for Primary Point of Interconnection (East Danville – Roxborough 230 kV)		
Attachment Cost	Construct a new three (3) circuit breaker 230 kV switching station physically configured in a breaker and half bus arrangement but operated as a ring-bus. Installation of associated protection and control equipment, 230 kV line risers and SCADA will also be required.	$7,000,000
Direct Connection Cost Estimate	East Danville - Roxborough 230 kV T-Line Cut In	$1,000,000
Non-Direct Connection Cost Estimate	230 kV Revenue Metering	$300,000
	Upgrade line protection and controls at the East Danville 230 kV substation	$300,000
	Generator lead first span exiting the POI station, including the first structure outside the fence	$1,250,000
	Upgrade line protection and controls at the Roxborough 230 kV substation	To be provided by DEP
Non-Direct Connection Cost Estimate	Reinforcement to mitigate the overload on the 05EDAN 1-05DANVL2 138 kV line. AD2-023 contributes to this overload. - Increasing the Danville - East Danville 138 kV circuit summer rating to 337/482 MVA. PJM Network Upgrade Number N6124. - Replace 5 Sub cond 2000 AAC 91 Str at Danville2 138kV station. Increase summer rating to 337/482. PJM Network Upgrade Number N7554.1 - Replace 3 Sub cond 2000 AAC 91 Str at East Danville 138kV station. Increase summer rating to 337/482. PJM Network Upgrade Number N7554.2	$7,989,000
	Total Estimated Cost for Project AD2-022/AD2-023	**$17,839,000**

Table 3

The estimates are preliminary in nature, as they were determined without the benefit of detailed engineering studies. Final estimates will require an on-site review and coordination to determine final construction requirements.

Figure 1: Point of Interconnection (East Danville-Roxborough 230 kV)

Single-Line Diagram

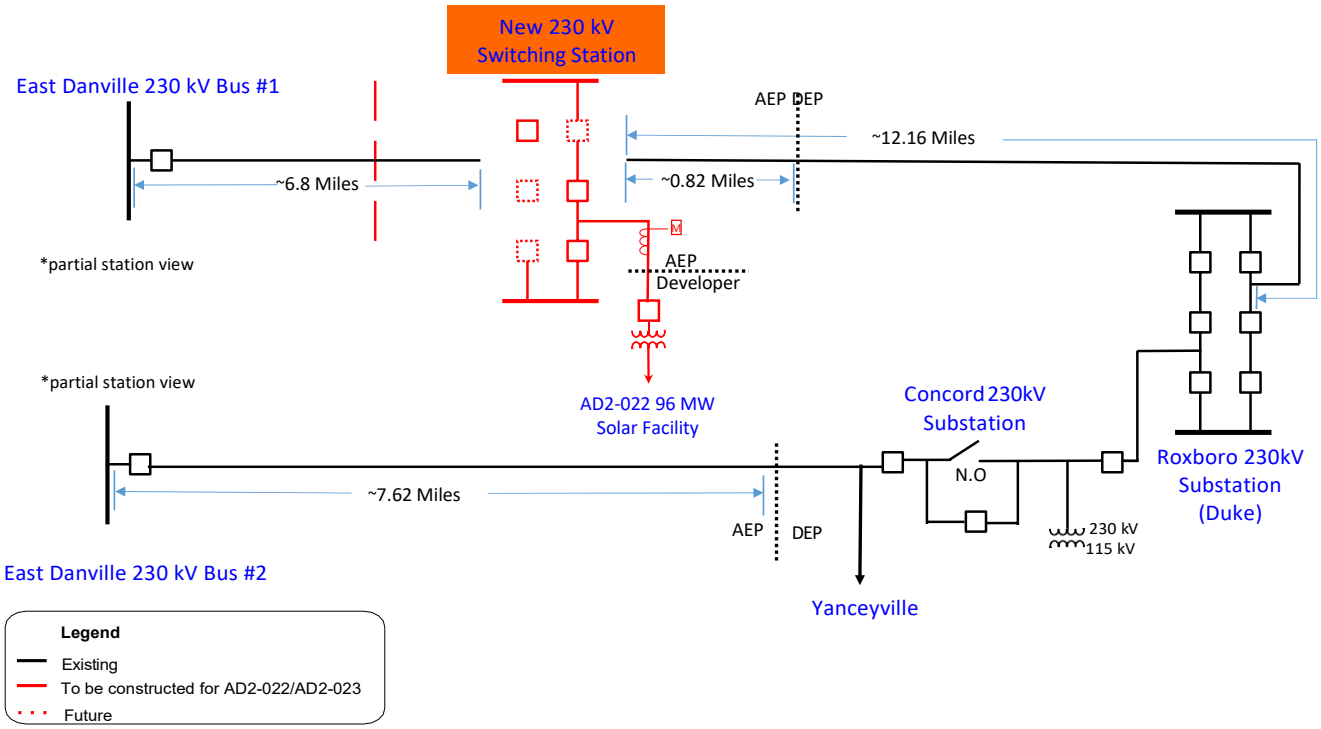
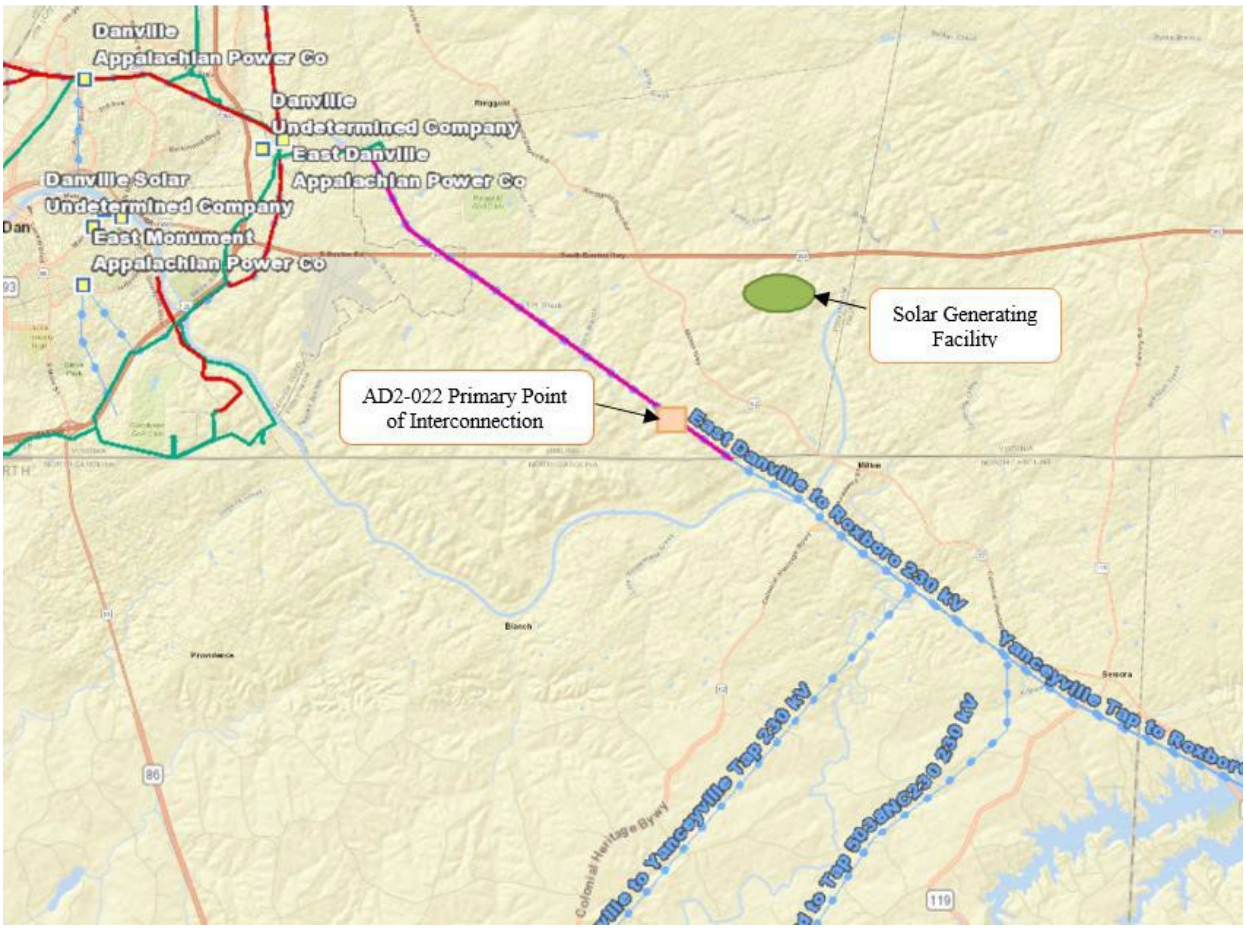


Figure 2: Primary Point of Interconnection (East Danville - Roxborough 230 kV)



Appendices

The following appendices contain additional information about each flowgate presented in the body of the report. For each appendix, a description of the flowgate and its contingency was included for convenience. However, the intent of the appendix section is to provide more information on which projects/generators have contributions to the flowgate in question. All New Service Queue Requests, through the end of the Queue under study, that are contributors to a flowgate will be listed in the Appendices. Please note that there may be contributors that are subsequently queued after the queue under study that are not listed in the Appendices. Although this information is not used "as is" for cost allocation purposes, it can be used to gage the impact of other projects/generators.

It should be noted the project/generator MW contributions presented in the body of the report and appendices sections are full contributions, whereas the loading percentages reported in the body of the report, take into consideration the commercial probability of each project as well as the ramping impact of "Adder" contributions.

Appendix 1

(AEP - AEP) The 05EDAN 1-05DANVL2 138 kV line (from bus 242631 to bus 242620 ckt 1) loads from 95.61% to 101.8% (AC power flow) of its emergency rating (415 MVA) for the line fault with failed breaker contingency outage of 'AEP_P4_#11112_05J.FERR 765_A1'. This project contributes approximately 26.47 MW to the thermal violation.

CONTINGENCY 'AEP_P4_#11112_05J.FERR 765_A1'
OPEN BRANCH FROM BUS 242511 TO BUS 242514 CKT 1 / 242511 05BROADF 765 242514 05J.FERR 765 1
OPEN BRANCH FROM BUS 242514 TO BUS 242520 CKT 1 / 242514 05J.FERR 765 242520 05J.FERR 500 1
OPEN BRANCH FROM BUS 242520 TO BUS 306719 CKT 1 / 242520 05J.FERR 500 306719 8ANTIOCH 500 1
OPEN BRANCH FROM BUS 242566 TO BUS 242567 CKT ZB / 242566 05BROADF 138 242567 05BROADX 138 ZB
END

Bus Number	*Bus Name*	*Full Contribution*
244012	*05PINNACLE*	*-2.13*
315131	*1EDGECMA*	*3.59*
315132	*1EDGECMB*	*3.59*
314557	*3BETHELC*	*0.34*
314554	*3BTLEBRO*	*0.36*
314572	*3EMPORIA*	*0.13*
314578	*3HORNRTN*	*1.17*
314582	*3KELFORD*	*0.29*
314603	*3SCOT NK*	*1.21*
314617	*3TUNIS*	*0.27*
314620	*6CASHIE*	*0.26*
314574	*6EVERETS*	*0.95*
932631	*AC2-084 C*	*2.49*
932632	*AC2-084 E*	*1.23*
932761	*AC2-100 C*	*3.59*
932762	*AC2-100 E*	*1.75*
932991	*AC2-123 C*	*-2.41*
933941	*AD1-017 C*	*0.79*
933942	*AD1-017 E*	*1.28*
933991	*AD1-022 C*	*2.63*
933992	*AD1-022 E*	*1.43*
934311	*AD1-055 C*	*1.01*
934312	*AD1-055 E*	*0.26*
934331	*AD1-057 C O1*	*4.*
934332	*AD1-057 E O1*	*2.13*
934341	*AD1-058 C*	*3.91*
934342	*AD1-058 E*	*0.99*

934521	*AD1-076 C O1*	*16.09*
934522	*AD1-076 E O1*	*8.19*
934611	*AD1-087 C O1*	*2.95*
934612	*AD1-087 E O1*	*1.38*
934621	*AD1-088 C*	*3.61*
934622	*AD1-088 E*	*1.7*
934991	*AD1-131 C*	*1.28*
934992	*AD1-131 E*	*0.86*
935171	*AD1-152 C O1*	*3.24*
935172	*AD1-152 E O1*	*2.16*
936171	*AD2-023 C O1*	*16.77*
936172	*AD2-023 E O1*	*9.71*
936261	*AD2-033 C*	*4.41*
936262	*AD2-033 E*	*2.94*
936361	*AD2-046 C O1*	*3.71*
936362	*AD2-046 E O1*	*1.7*
936401	*AD2-051 C O1*	*2.8*
936402	*AD2-051 E O1*	*1.2*
936481	*AD2-063 C O1*	*5.35*
936482	*AD2-063 E O1*	*3.54*
937481	*AD2-202 C O1*	*0.81*
937482	*AD2-202 E O1*	*0.46*
LTF	*AMIL*	*0.06*
LTF	*BLUEG*	*1.46*
LTF	*CANNELTON*	*0.15*
LTF	*CARR*	*0.08*
LTF	*CBM-S1*	*2.66*
LTF	*CBM-S2*	*17.22*
LTF	*CBM-W2*	*9.95*
LTF	*CLIFTY*	*8.83*
LTF	*CPLE*	*5.55*
LTF	*EDWARDS*	*0.28*
LTF	*ELMERSMITH*	*0.37*
LTF	*G-007A*	*0.52*
LTF	*GIBSON*	*0.38*
LTF	*NEWTON*	*0.49*
LTF	*RENSSELAER*	*0.06*
LTF	*TATANKA*	*0.12*
LTF	*TILTON*	*0.4*
LTF	*TRIMBLE*	*0.29*
900672	*V4-068 E*	*0.09*
LTF	*VFT*	*1.37*
917332	*Z2-043 E*	*0.34*
917342	*Z2-044 E*	*0.25*

917512	*Z2-088 E OP1*	*1.63*
918492	*AA1-063AE OP*	*1.32*
918512	*AA1-065 E OP*	*1.41*
918532	*AA1-067 E*	*0.29*
918562	*AA1-072 E*	*0.06*
919692	*AA2-053 E*	*1.29*
919702	*AA2-057 E*	*1.47*
LTF	*AA2-074*	*3.77*
920042	*AA2-088 E*	*3.15*
920592	*AA2-165 E*	*0.19*
920672	*AA2-174 E*	*0.15*
930402	*AB1-081 E*	*1.72*
930861	*AB1-132 C*	*4.77*
930862	*AB1-132 E*	*2.05*
931231	*AB1-173 C*	*0.75*
931232	*AB1-173 E*	*0.35*
931241	*AB1-173AC*	*0.75*
931242	*AB1-173AE*	*0.35*
923911	*AB2-031 C O1*	*0.74*
923912	*AB2-031 E O1*	*0.36*
923991	*AB2-040 C O1*	*2.43*
923992	*AB2-040 E O1*	*1.99*
924021	*AB2-043 C O1*	*1.17*
924022	*AB2-043 E O1*	*1.91*
924151	*AB2-059 C O1*	*4.72*
924152	*AB2-059 E O1*	*2.43*
924161	*AB2-060 C O1*	*3.34*
924162	*AB2-060 E O1*	*1.57*
924301	*AB2-077 C O1*	*0.75*
924302	*AB2-077 E O1*	*0.5*
924311	*AB2-078 C O1*	*0.75*
924312	*AB2-078 E O1*	*0.5*
924321	*AB2-079 C O1*	*0.75*
924322	*AB2-079 E O1*	*0.5*
924501	*AB2-099 C*	*0.19*
924502	*AB2-099 E*	*0.08*
924511	*AB2-100 C*	*3.36*
924512	*AB2-100 E*	*1.66*
925121	*AB2-169 C*	*2.19*
925122	*AB2-169 E*	*1.97*
925171	*AB2-174 C O1*	*2.29*
925172	*AB2-174 E O1*	*2.08*
925591	*AC1-034 C*	*3.06*
925592	*AC1-034 E*	*2.31*

925612	*AC1-036 E*	*0.52*
925781	*AC1-054 C*	*2.93*
925782	*AC1-054 E*	*1.35*
926051	*AC1-083 C*	*3.93*
926052	*AC1-083 E*	*6.41*
926071	*AC1-086 C*	*7.03*
926072	*AC1-086 E*	*3.2*
926201	*AC1-098 C*	*2.33*
926202	*AC1-098 E*	*1.39*
926211	*AC1-099 C*	*0.78*
926212	*AC1-099 E*	*0.46*
926271	*AC1-105 C*	*2.29*
926272	*AC1-105 E*	*1.14*
927021	*AC1-189 C*	*3.54*
927022	*AC1-189 E*	*1.77*
927141	*AC1-208 C*	*3.44*
927142	*AC1-208 E*	*1.53*
927251	*AC1-221 C*	*1.56*
927252	*AC1-221 E*	*1.56*
927261	*AC1-222 C*	*1.46*
927262	*AC1-222 E*	*1.39*