Project & Team

energy now

Distributed and Electric Power System Aggregation Model Determination and Field Configuration Equivalency Validation Testing (AAD-0-30605-09)

Presented by:

Murray W. Davis

DTE Energy Technologies Farmington Hills Michigan

Presented at the U.S. Department of Energy

Distributed Power Program

Quarterly Review Meeting

July 9-10, 2002

Madison, Wisconsin

DTE Energy

Project Team

energy|now

Organization	Team Members
DTE Energy Technologies Farmington Hills, Michigan	Murray W. Davis Ronald A. Fryzel (Retired)
Detroit Edison Detroit, Michigan	David Costyk Raluca E. Capatina-Rata Kenneth J. Pabian
Kinectrics Toronto, Ontario	Arun Narang E. Peter Dick

DTE Energy

Background and Objective

energy|now

Background

- Local electric distribution systems have not been designed to operate in parallel with local interconnected distributed power systems. As a result, issues arise concerning the compatibility, reliability, power quality, system protection, voltage dynamics, and safety.

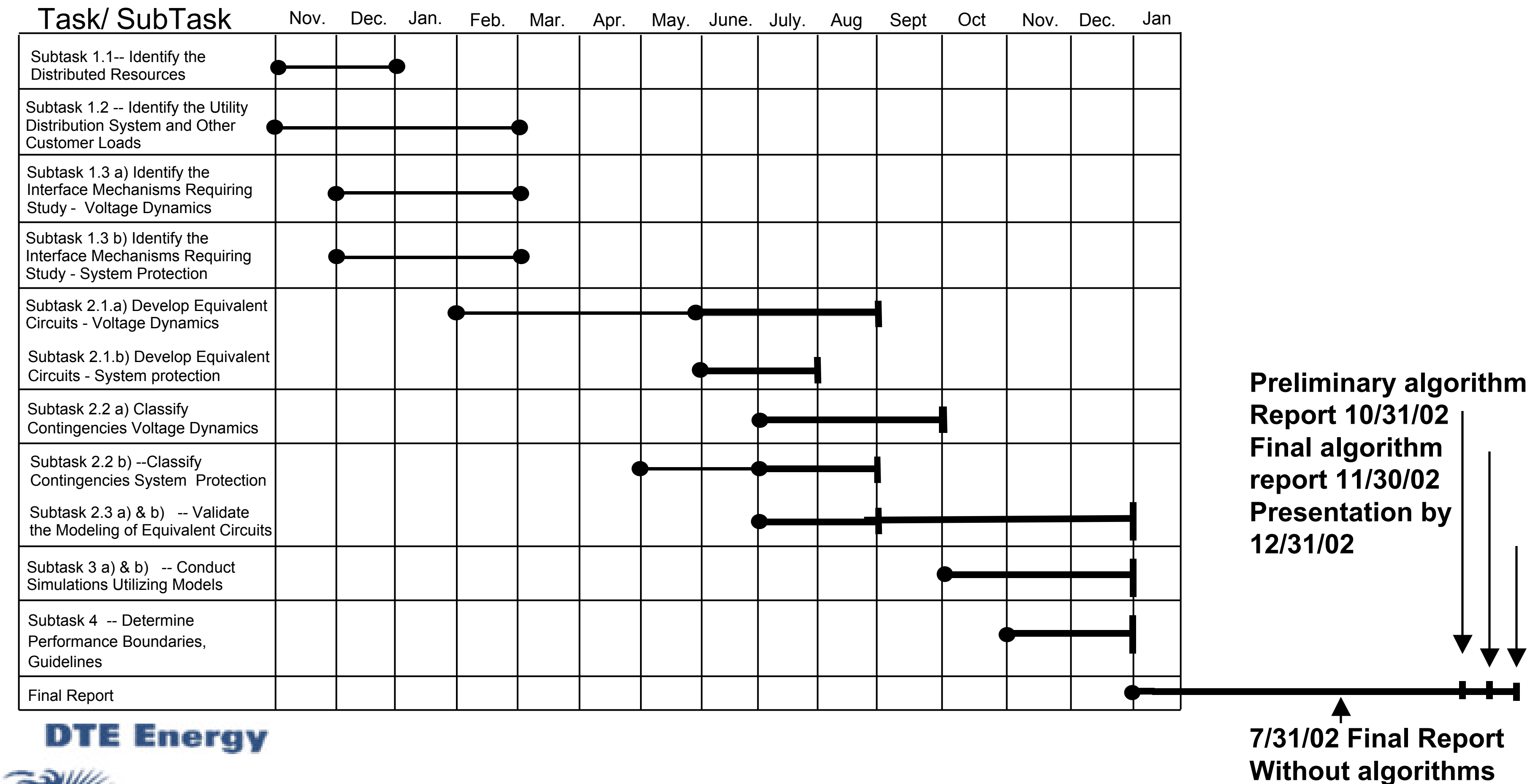
Objective:

- Address selected system integration issues arising from interconnecting distributed resources to the utility grid.
- Determine the DR system penetration limits imposed by the local grid due to a number of utility coordination issues, e.g., voltage dynamics, and system protection.

DTE Energy

energy|now

Project Schedule



DTE Energy

Approach

Approach

- Select two existing Detroit Edison distribution circuits for study
- Develop equivalent circuits and models
- Run simulations
- Determine DR penetration boundaries

Key Issues:

- System Protection by Detroit Edison
- Voltage & Stability by Kinectrics

DTE Energy

Approach Details

energy|now

Selected Circuits:

- 4.8kV D.C. 326 Argo (Ungrounded Delta)
- 13.2kV D.C 9795 Pioneer (Multi-grounded Wye)

Model and Study tools:

- Aspen, DEW (System Protection)
- EMTP (Harmonics), MATLAB (V. Reg), PTI PSS/E (Stability)

Validation techniques:

- Spot check among tools, Simplified hand calcs.
- Software tools are proven commercial packages

Key DR elements

- 1000 kVA synchronous generator
- 400 kW inverter based gas turbine
- 250 kW inverter based fuel cell

DTE Energy

List of 29 EEI System Impact Issues

energy|now

EEI Issues Studied by Detroit Edison

Issue		Issue	
→ 1	Improper Coordination	→ 16	Isolate DR for Upstream Fault
→ 2	Nuisance Fuse Blowing	17	Close-in fault Causes Voltage Dip - Trips DR
3	Reclosing out of Synchronism	18	Switchgear Ratings
4	Transfer Trip	19	Self Excited Induction Generator
5	Islanding	20	Long Feeder Steady State Stability
6	Equipment Overvoltage	21	Stability During Faults
7	Resonant Overvoltage	22	Loss of Exciters Causes Low Voltage
8	Harmonics	23	Inrush of Induction Machines Can Cause Voltage Dips
9	Sectionalizer Miscount	24	Voltage Cancelled by Forced Commutated Inverters
10	Reverse Power Relay Malfunctions	25	Capacitor Switching Causes Inverter Trips
11	Voltage Regulation Malfunctions	26	Flicker from Windmill Blades
12	Line Drop Compensator Fooled by DR's	→ 27	Upstream Single Phase Fault Causes Fuse Blowing
13	LTC Regulation Affected by DR's	28	Underfrequency Relaying
14a	Substation Load Monitoring Errors	29	Distribution Automation Studies
14b	Cold Load Pickup with & without DR's		
→ 15	Faults within a DR zone		

DTE Energy

→ **Impact issues related to system protection**

List of 29 EEI System Impact Issues

energy|now

EEI Issues Studied by Kinectrics

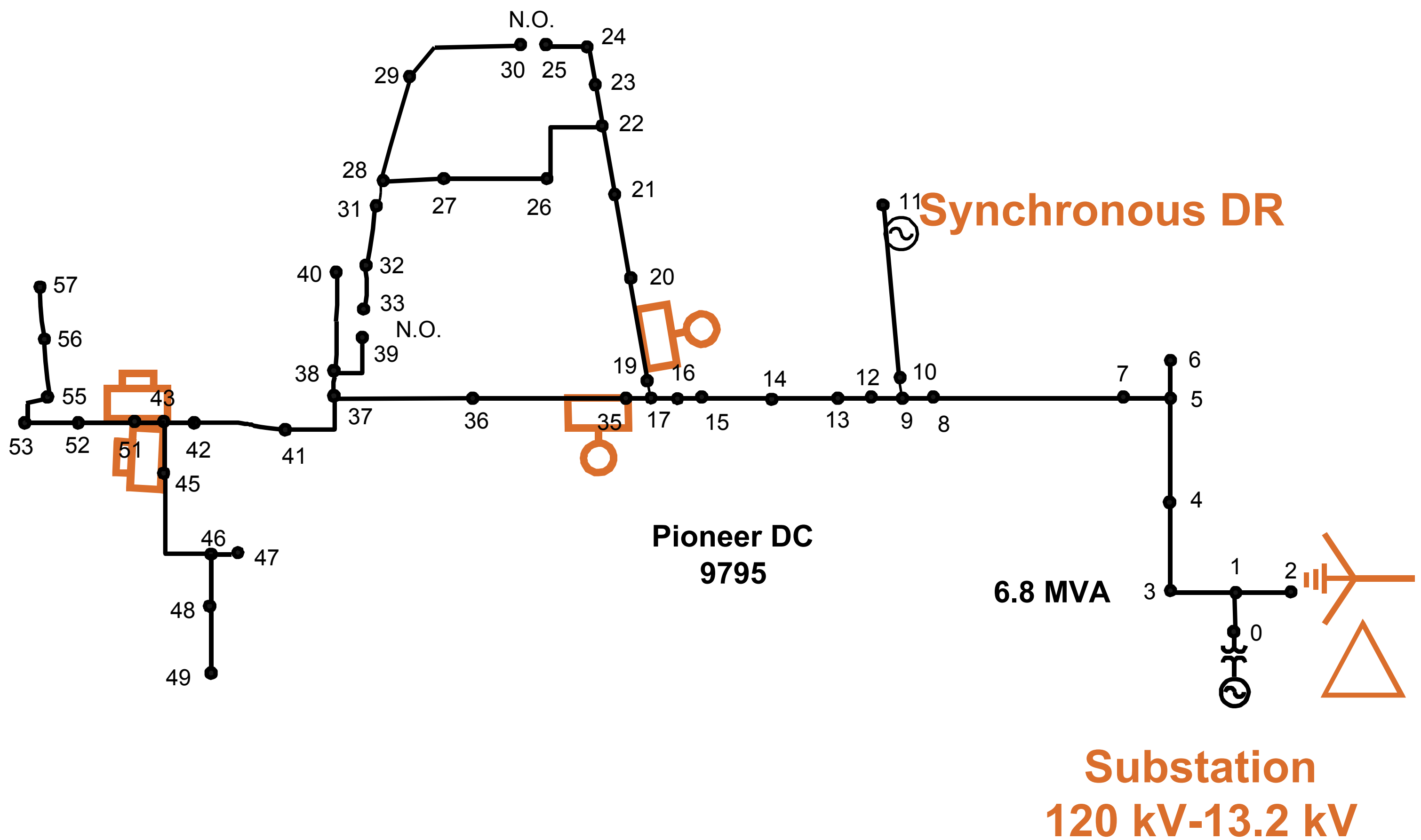
Issue		Issue	
1	Improper Coordination	16	Isolate DR for Upstream Fault
2	Nuisance Fuse Blowing	17	Close-in fault Causes Voltage Dip - Trips DR
3	Reclosing out of Synchronism	18	Switchgear Ratings
4	Transfer Trip	19	Self Excited Induction Generator
5	Islanding	20	Long Feeder Steady State Stability
6	Equipment Overvoltage	→ 21	Stability During Faults
7	Resonant Overvoltage	→ 22	Loss of Exciters Causes Low Voltage
→ 8	Harmonics	23	Inrush of Induction Machines Can Cause Voltage Dips
9	Sectionalizer Miscount	→ 24	Voltage Cancelled by Forced Commutated Inverters
10	Reverse Power Relay Malfunctions	25	Capacitor Switching Causes Inverter Trips
→ 11	Voltage Regulation	26	Flicker from Windmill Blades
12	Line Drop Compensator Fooled by DR's	27	Upstream Single Phase Fault Causes Fuse Blowing
13	LTC Regulation Affected by DR's	28	Underfrequency Relaying
14a	Substation Load Monitoring Errors	29	Distribution Automation Studies
14b	Cold Load Pickup with & without DR's		
15	Faults within a DR zone		

DTE Energy

→ **Impact issues related to voltage dynamics and stability**

D.C 9795 Pioneer Overview

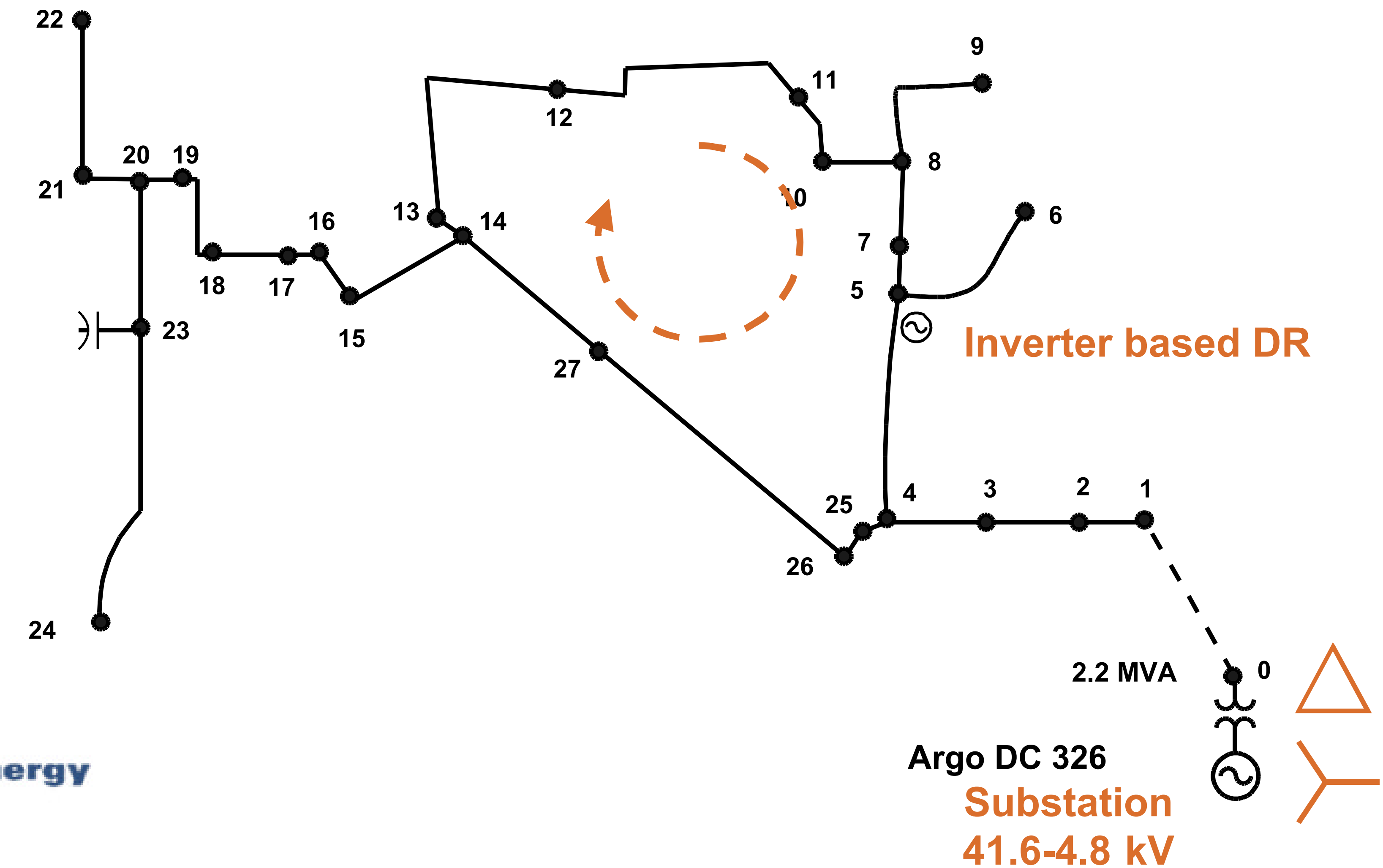
energy|now



DTE Energy

D.C 326 Argo Overview

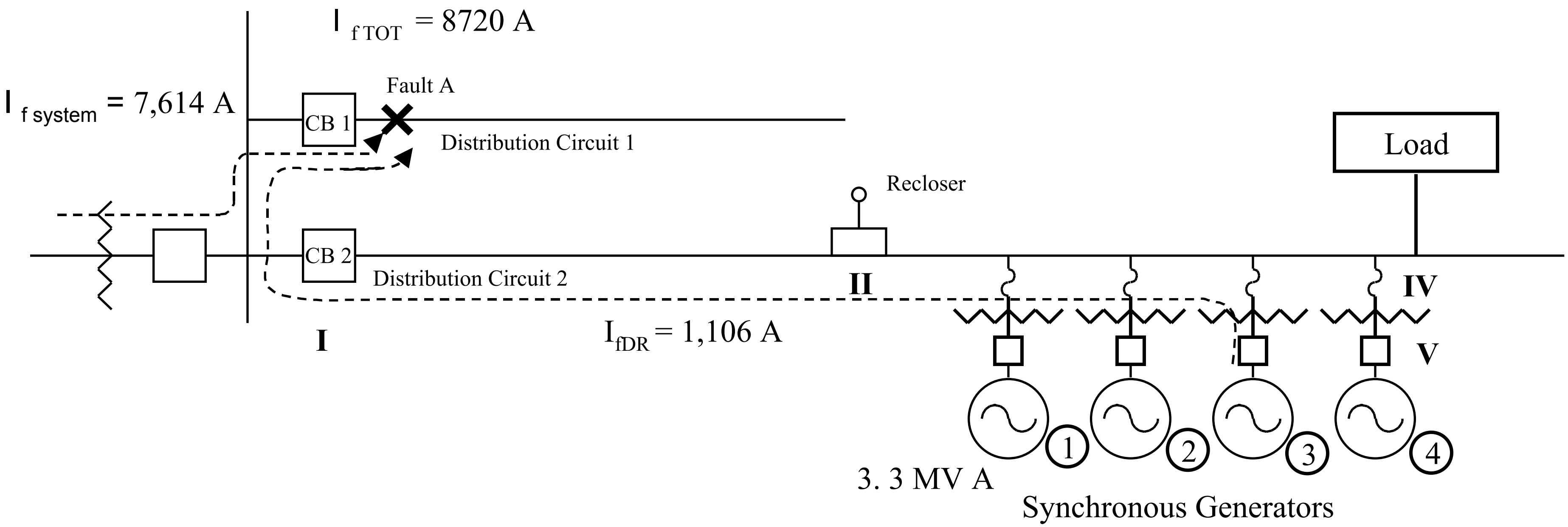
energy|now



DTE Energy

Issue 1: Improper Coordination One-Line

Example



1. For various fault current levels, fuse sizes, recloser sizes and breaker trip currents determine limits of DR penetration to cause inselectivity

2. Aspen, DEW and hand calculations were consistent.

DTE Energy

Issue 1: Improper Coordination Question

energy|now

Question:
What is the limit of DR size for a specific combination of protective devices?

The 40 k and 100k fuses were alternately substituted for the 140 A recloser.

Maximum penetration limits were determined while maintaining coordination with the 1000 A breaker trip setting.

DTE Energy

Issue 1: Improper Coordination Results

energy|now

Study Results:

Aspen studies on D.C. 326 Argo indicate that the DR penetration size limits are as follows:

DC 326 Argo (4.8 kV)

	Maximum Size (MVA)		
	Distance from Substation		
Fuse Size	Near end	Mid pt.	Far end
40k	0.47	0.5	0.55
100k	1.25	1.42	2.5
140 A recloser	1.9	2.5	Note 1

Note 1: The line impedance limits current to a value such that a large generator (e.g. 5 MVA) will not cause inselectivity

Table III . Maximum DR Sizes on DC 9795 Pioneer (13.2 kV)

	Maximum Size (MVA)		
	Distance from Substation		
Fuse Size	Near end	Mid pt.	Far end
40k	1.25	1.3	1.35
100k	3.3	3.6	4
140 A recloser	5.1	5.9	7.2

DTE Energy

Issue 1: Improper Coordination Relay and Recloser curves

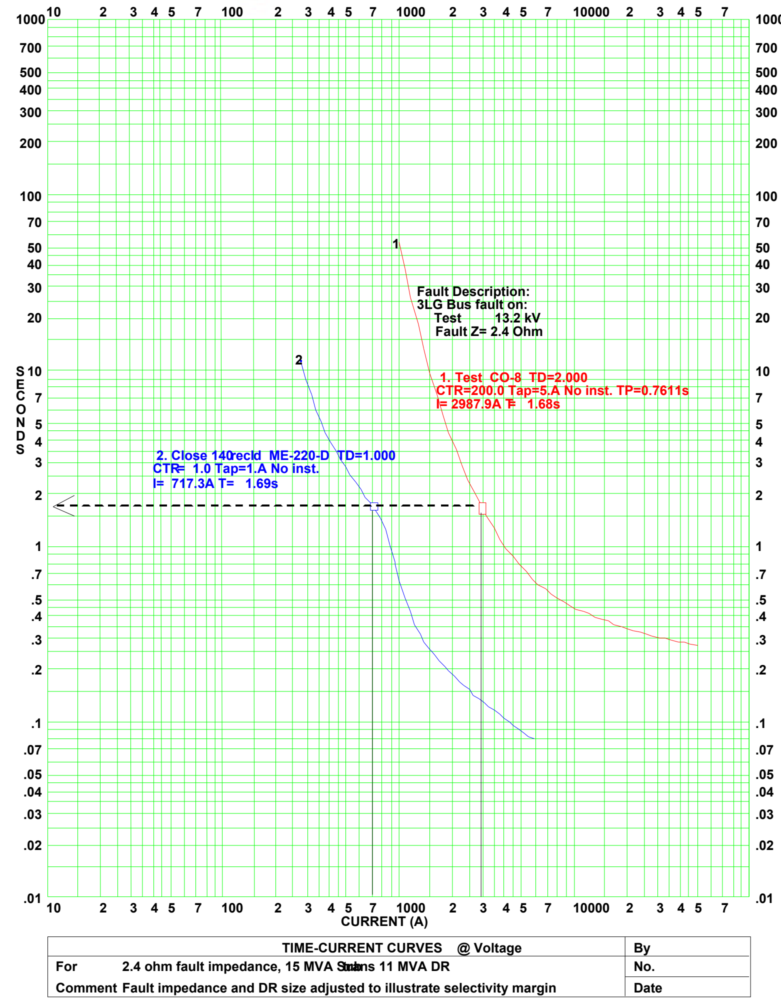
energy|now

Plot does not permit viewing a selectivity range

Plot does not show the effect of increasing the DR size

To make a plot that shows this effect:

- Determine breaker trip time for a current
- Determine recloser current for that same time
- Calculate system current (Breaker-Recloser)
- Plot each Recloser Current vs System current over a range

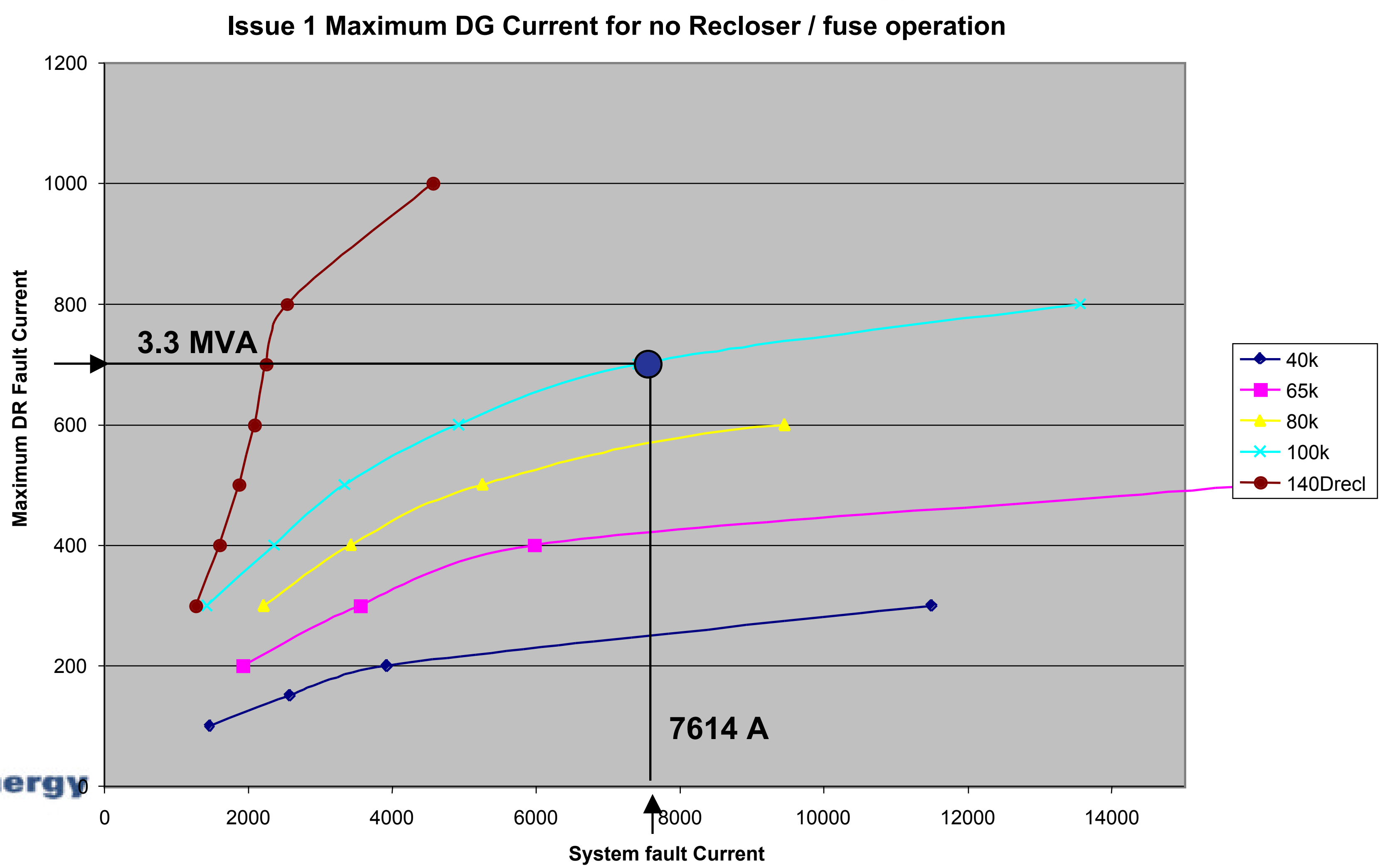


Plot of time current curves for substation breaker relay and 140a recloser.

DTE Energy

Issue 1 Improper Coordination
Penetration Limit Results

energy|now

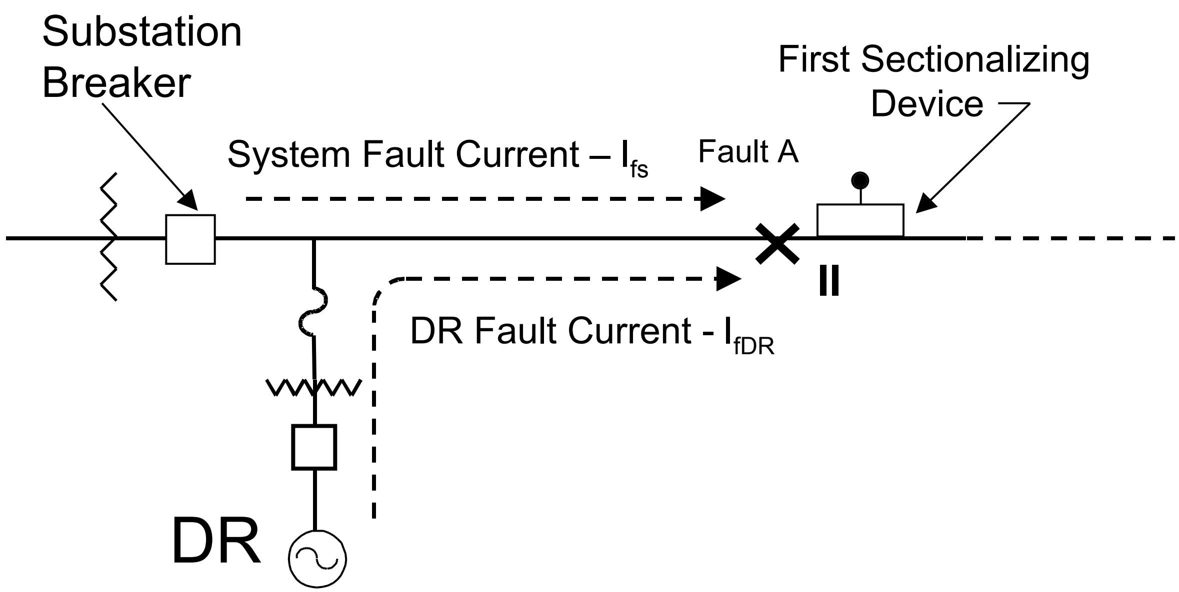


DTE Energy

Issue 1 Fault Detection Sensitivity One-Line

Scenario

- **Fault at point A as shown below.**
- **Fault is near the line protection device that has the least available fault current at its location.**
- **The substation breaker will typically not be required to sense faults beyond this device.**
- **Fault current contribution from DR reduces fault contribution from substation**
- **Protective device at substation takes longer to trip or does not trip until DR trips**



DTE Energy

Issue 1 Fault Detection Sensitivity Question and Results

energy|now

Question

For the existing relay settings, what is the maximum DR size that can be connected and permit a minimum of 2000 amps fault current to flow from the existing source?

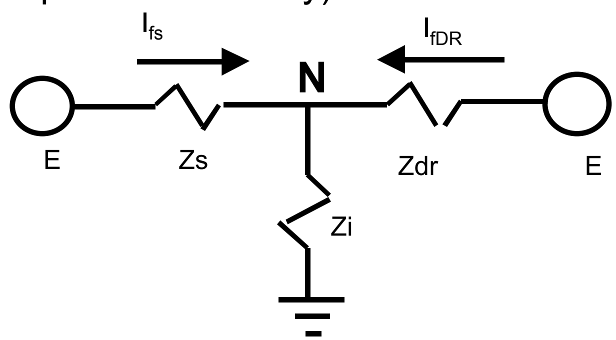
(Requiring 2000 amperes provides a safety margin for the existing relay trip settings of 1000 A)

Maximum Generation Penetration			
3 phase faults			
Protective Device Location	Pioneer	Protective Device Location	Argo
Mid Pt Node 17	80 MVA	Mid Pt Node 15	2.5 MVA
Line to Ground Faults			
Protective Device Location	Pioneer	Protective Device Location	Argo
Mid Pt Node 17	5.3 MVA	Mid Pt Node 15	Does not Apply

DTE Energy

Issue 1: Improper Coordination
Infeed Table

Table to Show Source Current (Is) and DR Current (Idr)
for various Per Unit Source and DR Impedances
(Three phase faults only)



Make Entries in Blue Shaded Area only!!!

MVA Base=	10	
kV Base =	13.2	
I base =	437.3866	
Z base =	17.424	
DR PU Z =	0.2	(to calculate DR size)
All Z in P.U.		E= 1.0
Zs=	**0.057**	

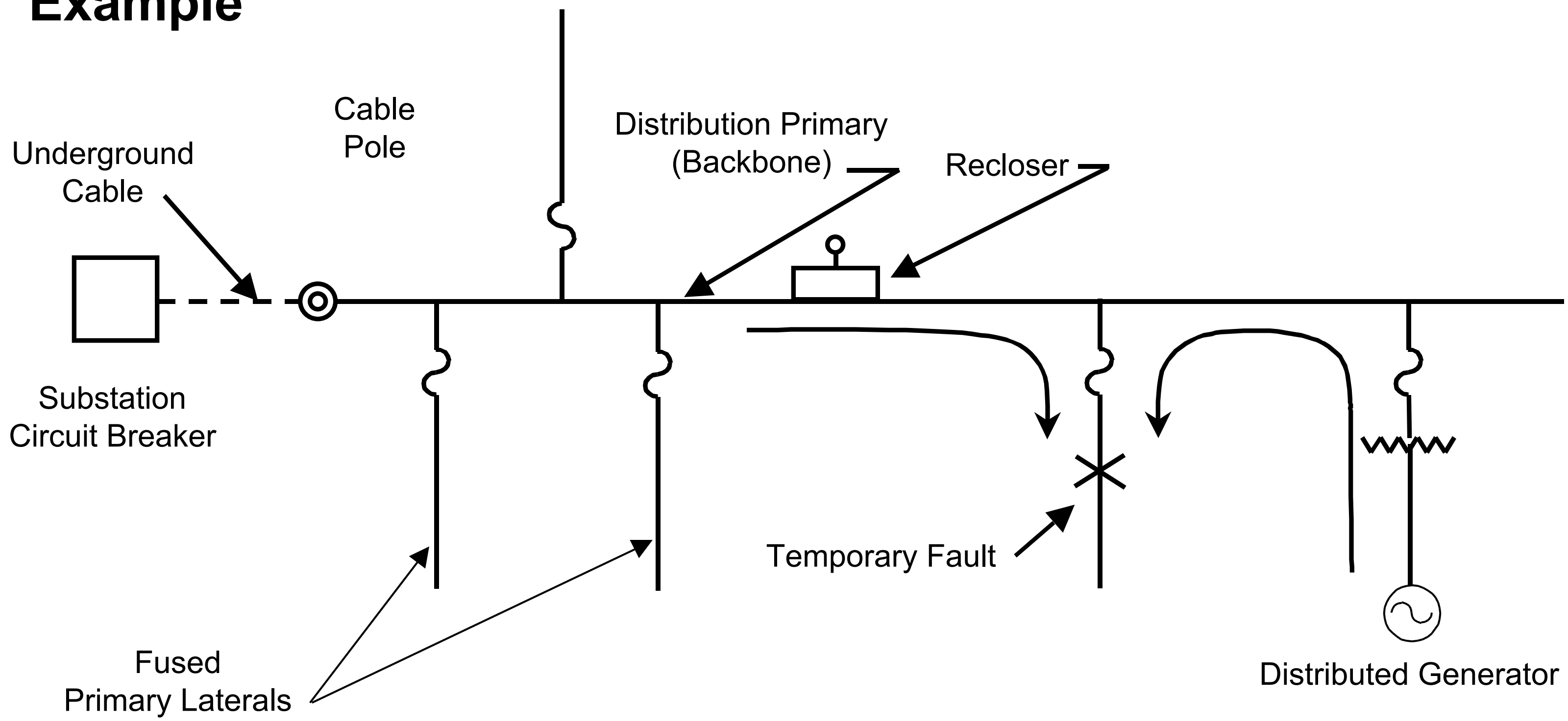
Is=Zdr/(Zdr+Zs)E/((Zdr*Zs)/(Zdr+Zs)+Zi)
Id=Zs/(Zdr+Zs)E/((Zdr*Zs)/(Zdr+Zs)+Zi)
Zdr=(Zi*Zs)/((E/Is-(Zs+Zi))

		Charted			Charted			Charted	Charted
	Zi ->	**0.030**	**0.050**	**0.060**	**0.054**	**0.080**	**0.090**	**0.127**	**0.200**
DR MVA size	**Zdr**				**Is**				
80	**0.025**	2814.6	1979.1	1723.4	1881.4	1369.4	1241.9	923.6	613.4
66.66666667	**0.03**	3037.4	2165.3	1893.4	2061.7	1513.4	1375.4	1028.4	686.6
50	**0.04**	3371.0	2453.8	2159.9	2342.3	1742.6	1589.1	1198.4	807.0
10	**0.2**	4577.6	3607.3	3261.6	3478.3	2737.1	2533.4	1986.4	1393.0
4	**0.5**	4837.3	3881.0	3531.9	3751.2	2993.3	2781.3	2203.7	1563.2
2	**1**	4930.5	3981.7	3632.2	3851.9	3089.8	2875.1	2287.1	1629.6
0.2	**10**	5017.6	4076.9	3727.5	3947.4	3182.0	2965.1	2367.8	1694.4

Issue 2: Nuisance fuse blowing
One-Line

energy|now

Example



1. For various fault current levels, fuse sizes, recloser sizes and breaker trip currents determine limits of DR penetration to cause inselectivity
2. Compare Aspen and DEW results

DTE Energy

Issue 2: Nuisance fuse blowing
Question and Results

Question:

What is the limit of DR size for any specific combination of fuse and recloser?

DC 326 Argo

	Maximum Generator Size (MVA)		
	Distance from Substation		
Fuse Size	Near end	Mid pt.	Far end
65k	Note 1	Note 1	0.3
80k	Note 1	Note 1	1.0
100k	Note 1	Note 1	2.0

Note 1: The system fault current is too high to save the fuses even without the DR on line (system fault current = 7600 A at substation).

DC 9795 Pioneer

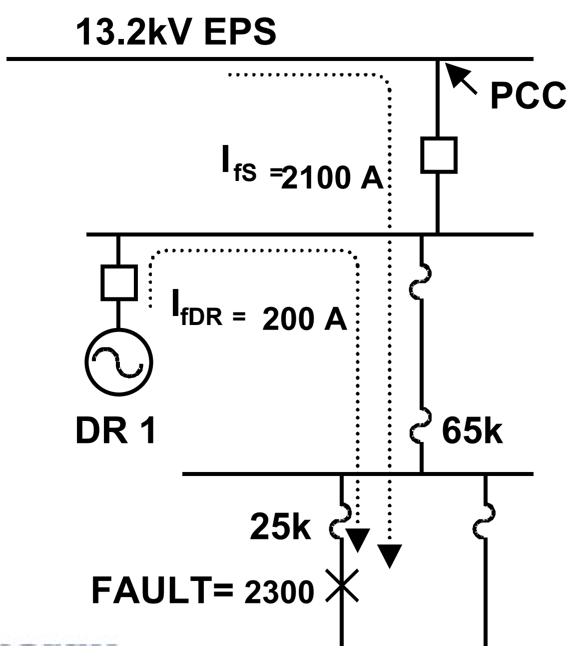
	Maximum DR Size (MVA)		
	Distance from Substation		
Fuse Size	Near end	Mid pt.	Far end
65k	Note 1	Note 1	Note 1
80k	Note 1	Note 1	Note 1
100k	Note 1	Note 1	1.0

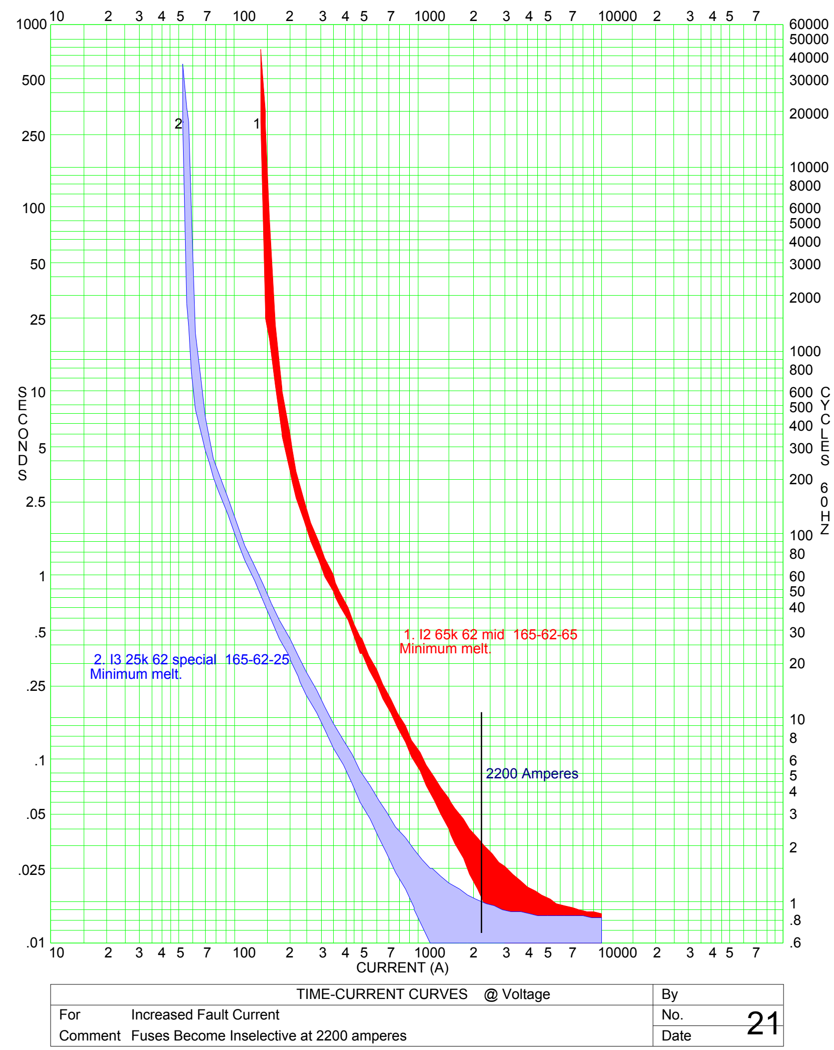
DTE Energy

Issue 15:Faults Within the DR Zone: Question

Question:

What is the effect of increased fault current on selectivity ?





- 2200 Amperes is a selectivity issue. Data in curves shows no 75% margin.

Issue 15:Faults Within the DR Zone: Results

Study Results:

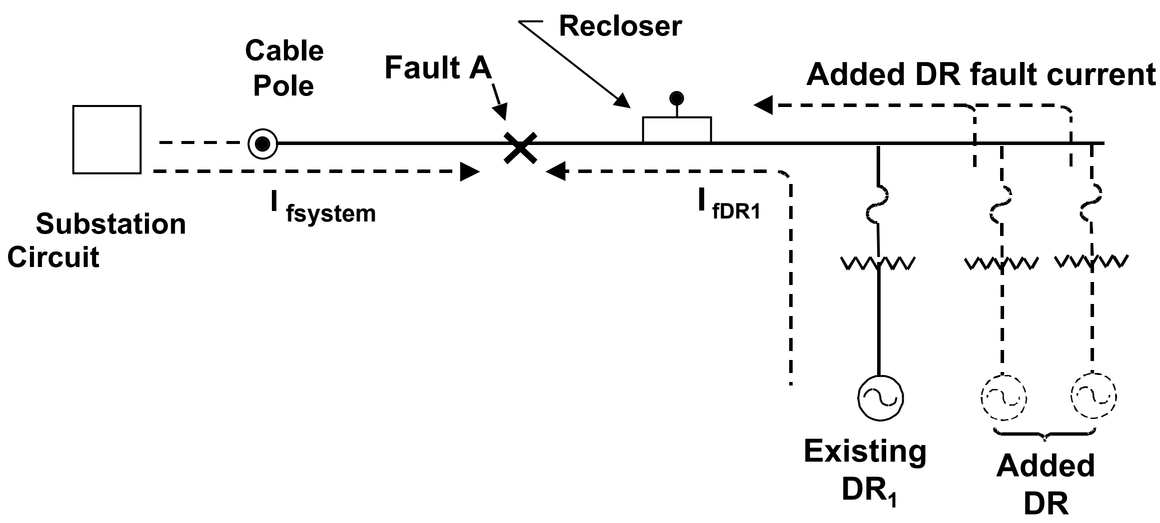
In this case the DR fault current limit is less than 100 A or 2.2 MVA @ 13.2 kV, which results in a maximum DR size of 0.45 MVA. This is an issue that prevails for all electric power systems with high system fault current contributions.

DTE Energy

Issue 16: Isolate DR for Upstream Fault: Diagram

Scenario:

- Fault occurs on the circuit at "A" between the substation and the recloser
- Current flows from the substation transformer (I_{fs}) and from the DR (I_{fDR}) to the fault
- The current from DR 1 is sensed by a local device (fuse) and the recloser
- The current from the additional DR's on the circuit may cause the recloser to operate



DTE Energy

Issue 16: Isolate DR for Upstream Fault: Question

energy|now

Question:

How much current from additional DR's will cause the recloser or fuse on the line to operate before the protective devices (fuse) operate at the existing DR?

Study Results

DC 326 Argo

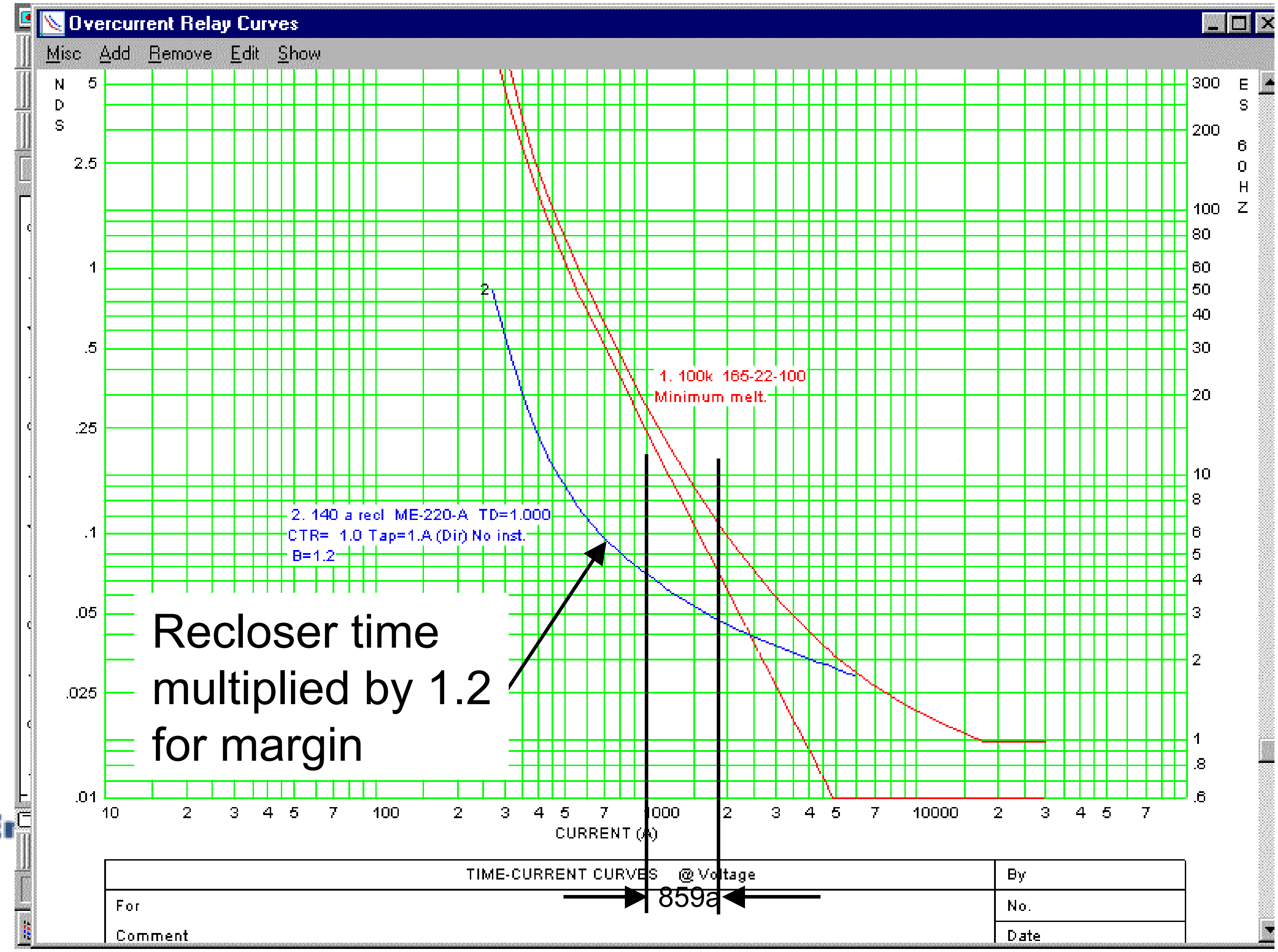
	Maximum Added Generator Size (MVA)		
	Distance from Substation		
Existing DR Fuse Size Combination	Near End	Mid Point	Far End
40k-0.5MVA	1.3	1.3	1.3
40k-1.0 MVA	3.5	3.5	3.5
40k-3.0 MVA	Greater than 10	Greater than 10	Greater than 10
80k-0.5MVA	0.3	0.3	0.3
80k-1.0 MVA	0.75	0.75	0.75
80k-3.0 MVA	Greater than 10	Greater than 10	Greater than 10

DC 9795 Pioneer

	Maximum Added Generator Size (MVA)		
	Distance from Substation		
Existing DR Fuse Size Combination	Near End	Mid Point	Far End
40k-1MVA	3.1	3.2	3.2
40k-3 MVA	12	12	12
40k-5 MVA	Over 20	Over 23	Over 23
80k-1 MVA	0.3	0.3	0.3
80k-3 MVA	2.2	2.2	2.2
80k-5 MVA	5	5	5

DTE Energy

Issue 2: Nuisance fuse blowing
Recloser and Fuse Curves



Issue 8: Harmonics - Question

KINECTRICS

Question:

What are the maximum sizes of inverters that can be connected at different nodes on the circuit and meet permissible industry harmonic limits?

The maximum permissible voltage distortion at any single frequency is 3%

Characteristics of Studied Feeders

	ARGO	PIONEER
Operating Voltage	4.8 kV (3-wire)	13.2kV (4-wire)
Station Short-circuit capacity	70 MVA	174 MVA
Peak feeder load	2.2 MVA (0.96 pf)	6.8 MVA (0.9pf)
Off- peak load	0.5 MVA	1.4 MVA
Downstream Transformer regulation	None	None
Capacitor Compensation	Unswitched 600 kVAr at Node 23	Switched 3MVAr at supply bus

Issue 8: Harmonics - Results

Results:

Harmonic DR Maximum Size

Line Commutated Inverter (<11^{th} order)			
		Argo	Pioneer
Total Capacity limit		1.2 MVA	870 kVA
Pulse Width Modulated (PWM) Inverter (> 35^{th} Order)			
	Argo		Pioneer
	With Capacitor	Without Capacitor	(1)
Single Unit Limit	2.3 MVA	230 kVA	870 kVA
Multiple Unit Limit	9.2 MVA	920 kVA	3.48 MVA

Note (1) The 3 MVAr capacitor at Pioneer has no effect on harmonic distortion from PWM inverters because the frequencies excited by PWM inverters are much higher than the resonant mode caused by this capacitor.

Issue 11: Voltage Regulation - Question

Question #1

What are the locations on a circuit and injections from DR's which will not cause voltage limit violations?

Notice the DR is operating at a fixed unity P.F. This will allow the DR to track the system voltage and not actively regulate the distribution circuit voltage.

Question #2

What are the maximum P (real power) and Q (reactive power) injections from the DR which will not cause voltage limit violations?

Notice in this case the DR is not necessarily operating at a fixed P.F. and thus Would affect system voltage profile.

Issue 11: Voltage Regulation - Results

KINECTRICS

Results: #1

Maximum DR Size to Maintain Steady State Voltage to Within ± 5% of Nominal

Argo: Far end - - 2.0 MVA

Pioneer: Far end - - 14 MVA

Results : #2

Maximum DR Size to Maintain Steady State Voltage to Within ± 5% of Nominal
Using Active Voltage Regulation (P+j Q) - (i.e. @ P.F. = .8)

Argo: Far End -- 4.5 MVA

Pioneer: Far End -- >30 MVA

Issue 21: Transient Stability – Question/Results

KINECTRICS

Question:

What is the critical clearing time for synchronous generators to remain stable when faults occur close to the DR and remote from the DR on the same feeder?

Results:

Clearing Time to Maintain Stability

Feeder	Location of DR		3 Ph Fault Location and Clearing Time	
	Near End	Far End	Near End	Far End
Argo		Node 24	0.25 s	
	Node 5		0.10 s	
	Node 5 .5 p.u. voltage			1.0 s
Pioneer		Node 57	0.11 s	
	Node 5		0.11 s	
	Node 11 .5 p.u. voltage			1.5 s

Notes:

(1) Multiple DR's tend to increase the stability or extend critical clearing time

(2) Different load representations of (a) 50% constant impedance and 50% constant power and (b) 100% constant impedance have little effect on results.

(3) Results were based on H= 1kW*sec / kVA, higher machine inertia constants would extend fault clearing times proportionately.

Issue 22: Loss of Exciter - Question/Results

Question:

What is the maximum DR size that can be installed at certain nodes and not exceed the 10% voltage dip limit created by loss of excitation?

Results:

Maximum DR Size to Limit Voltage Dip to 10% Due to Loss of Excitation

Argo:	Substation Bus -- 6.5 MVA	Far end - - 0.5 MVA
Pioneer:	Substation Bus -- 16.2 MVA	Far end -- 3.9 MVA

Major Findings

energy|now

1. The system voltage has a significant impact on the maximum DR size (or aggregated size) which can be connected to a circuit – the size ratio is near the ratio of system voltages.
   e.g. Issue # 1: Improper Coordination $\frac{4.8\ kV}{0.47\ MVA}$ $\frac{13.2\ kV}{1.25\ MVA}$

2. Type of fault (3Ø vs. Line to Ground) has a heavy influence on determining the size of DR.
   e.g. Issue # 1: Fault detection sensitivity

Mid Point	3Ø fault	L – G fault
on Pioneer ckt.	80 MVA	5.3 MVA

3. Nuisance fuse blowing tends to limit DR sizes to less than 2 MVA for compact circuits fed from 15 MVA substation transformers (high system fault current = 7600 A at substation)

4. Harmonic analysis maybe required for inverters because of the wide range of acceptable DR sizes (i.e. 820 kVA _ 9.2 MVA)

5. Active voltage regulation using both real and reactive injection tends to allow larger sizes of DR's than DR's which stack system voltage

DTE Energy

Major Findings

energy|now

6. Location of DR's circuit is very important in determining the voltage limits for loss of excitation DR limits

		Bus	Far End
(e.g.	Argo	6.5 MVA	.5 MVA
	Pioneer	16.2 MVA	3.9 MVA)

7. If critical clearing time is .1 seconds or less, then stability should be maintained; the larger the machine inertia (H) the more stable the unit.

DTE Energy