Overview of the UWIG Distributed Wind Project

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Launching the Distributed Wind Project

UWIG R&D Survey

- Periodic survey of member R&D needs conducted
- Members asked to identify top concerns related to adding increased wind capacity
- Top two priorities identified by members are:
  - Operating impact cost of large wind plants
  - Impact of distributed wind on distribution feeders
- UWIG initiated funded research projects to address these concerns

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Distributed Wind Impacts Project

- Large funded research project to develop software tools and application guides for installation of wind turbines on distribution systems
- Provide guidance and direction for new efforts through resource materials in the form of measurements database and case study library
- Driven by recognition that analytical tools for distribution system planning, design, and operation with radial distribution feeders may no longer be valid for feeders interconnected to distributed generators

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DW Project Objectives

- Develop a set of tools to assist distribution and planning engineers in the assessment and application of wind generation on the distribution system.
- Provide assistance in meeting compliance with IEEE P1547 DG Interconnection Standard and flicker standards.
- Provide guidance and direction for new efforts through resource materials in the form of a measurements database and a case study library

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Project Deliverables

- Information Tools
  - IEEE 1547 guide, flicker guide, measurement database, case studies
- Engineering Software Tools
  - Feeder Simulator
  - Flicker Calculator
  - Economics Applet
  - Multispeak Data Importer

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Project Informational Tools

- IEEE P1547 Application Guide for Wind Generation
  - Practical recommendations for meeting guidelines concerning voltage regulation, harmonics, and protection requirements
- Voltage Flicker Application Guide
  - Describe in detail the phenomena of flicker, measurement and calculation techniques (including IEC), and mitigation techniques
- Distributed Wind Generation Measurement Database
  - Web access to UWIG member distributed wind measurement data
- Distributed Wind Generation Case Studies
  - Monitored data and/or simulation will be used to demonstrate technical and economic analysis for existing and/or proposed UWIG member distributed wind installations

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Project Engineering Software Tools

- Feeder Simulator
  - Use a simple feeder and wind plant model to analyze voltage regulation
  - Evaluate impact of turbine installation on existing protection schemes
- IEC Flicker Compliance Evaluator
  - Use a simple feeder and wind plant model to analyze voltage flicker against specified limits
- Economic Screening Applet
  - Compare economic merits of alternative sites
- Data File Importer
  - Convert WindMil/MultiSpeak2 data files in format that can be inputted into tools

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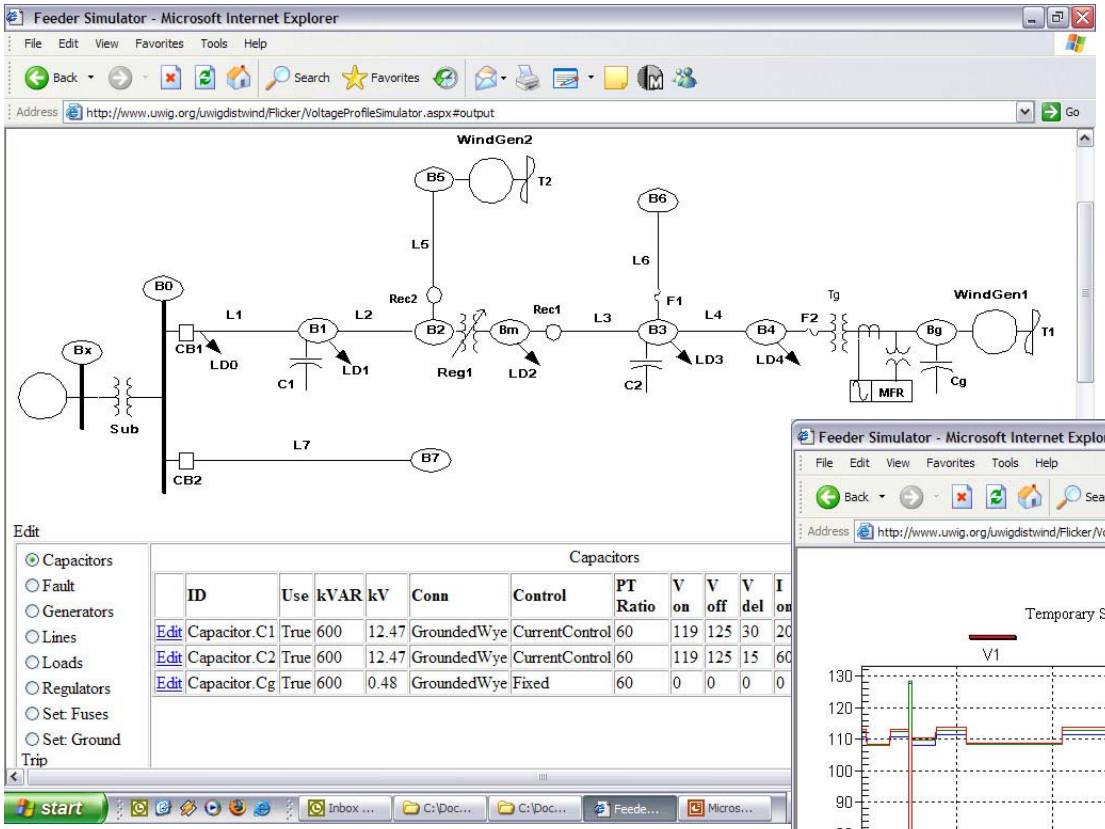
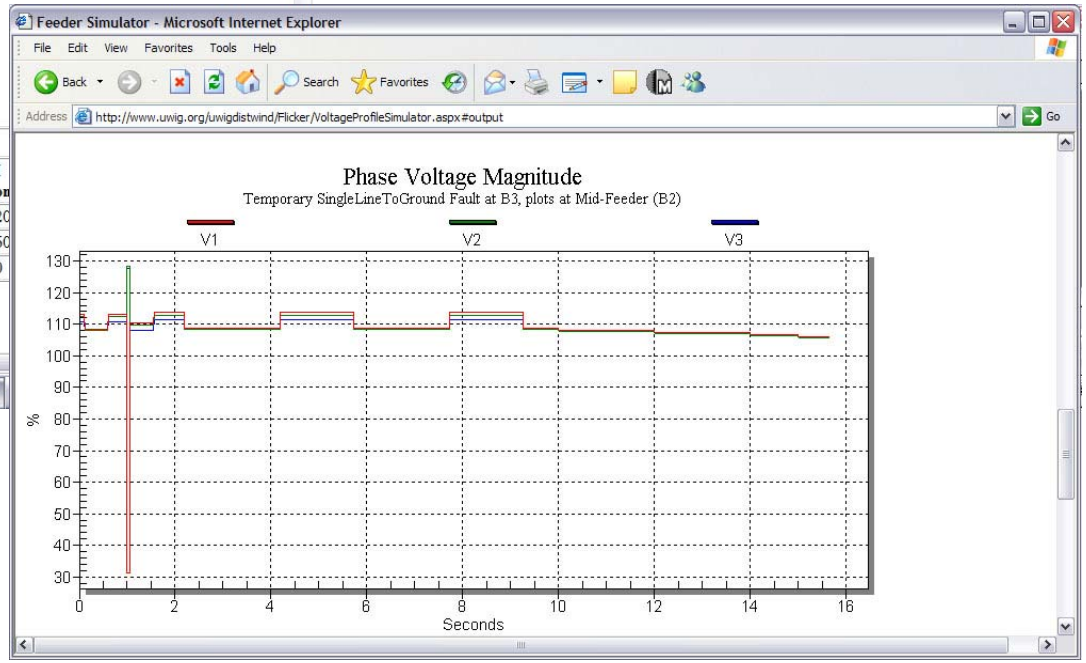
Distributed Wind Impacts Project





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Project Delivery Structure

- All project deliverables provided through project website
  - www.uwig.org/uwigdistwind/
- Unprotected front page describing project
- Protected project member page
  - News and notes
  - Progress reports
  - Completed and interim deliverables

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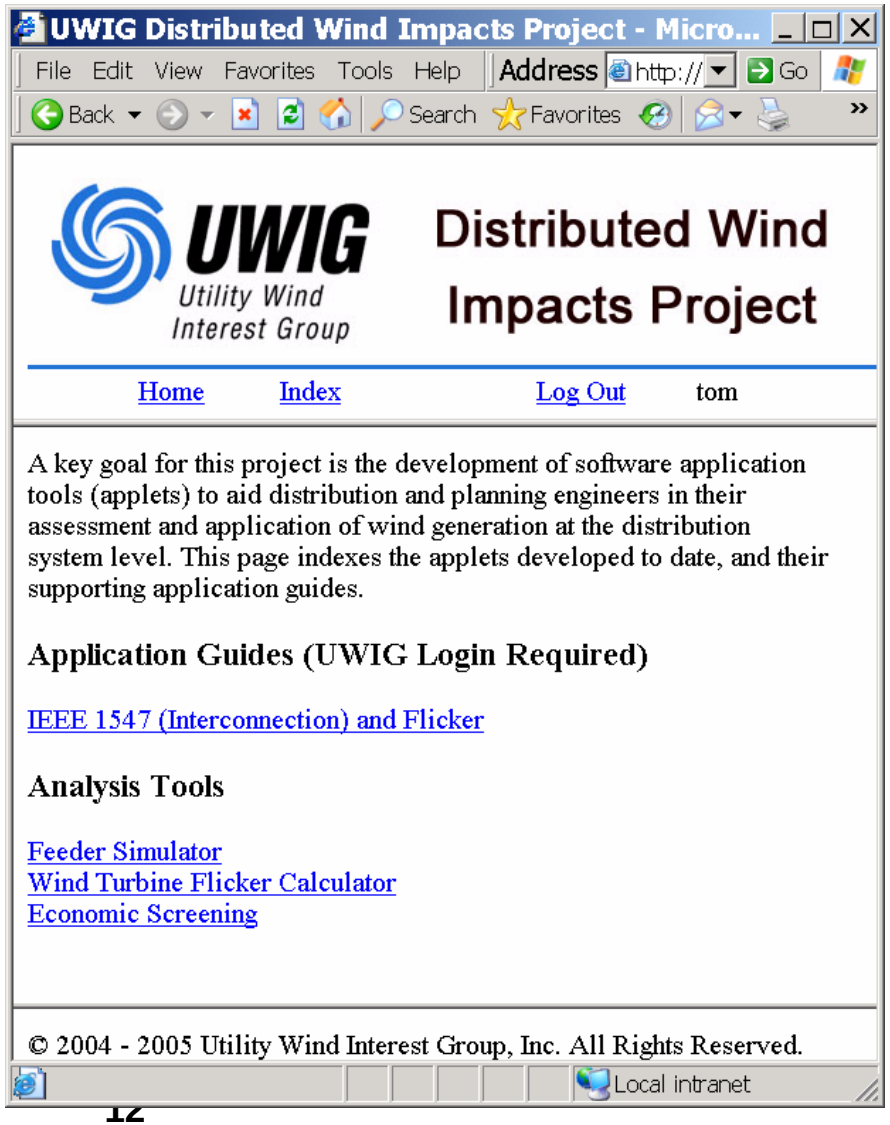
Applet Overview

Members-Only Index Page

- http://www.uwig.org/distwind/default.htm
- Click "Analytical Applications"



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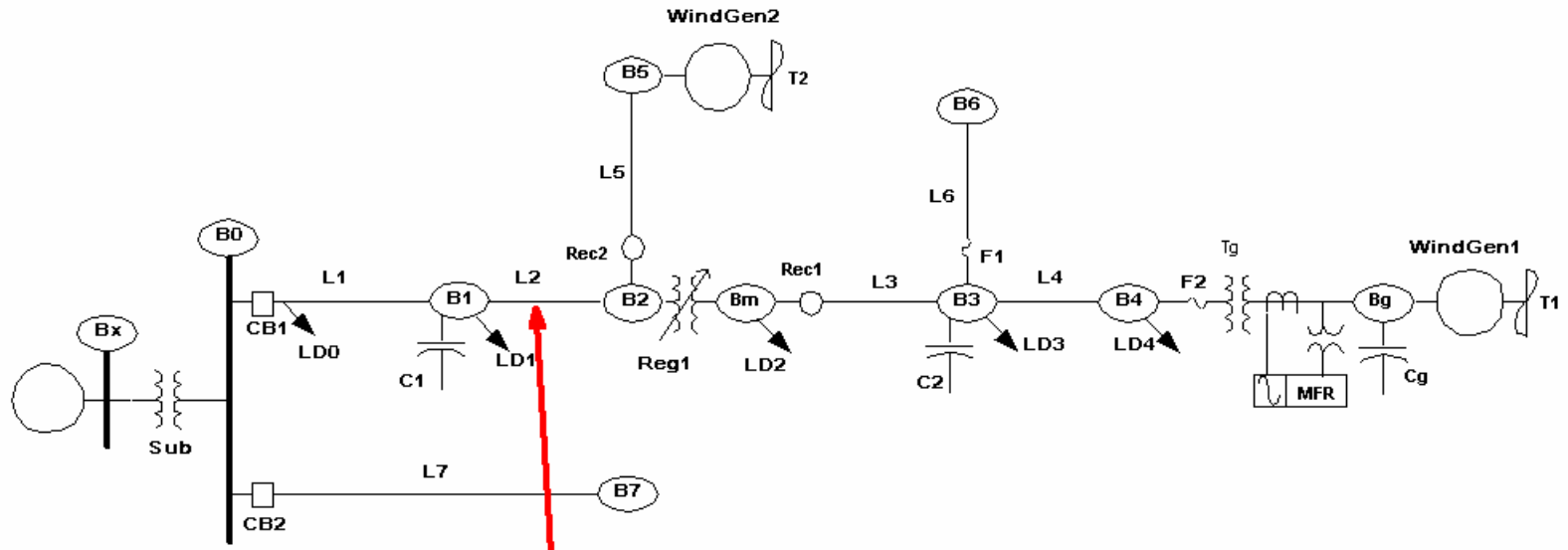
Feeder Simulator GUI



Edit

- Capacitors
- Fault
- Generators
- Lines
- Loads
- Regulators

Lines

	ID	Type	kft
Edit	Line.L1	Unbalanced 336 ACSR	10
Update Cancel	Line.L2	Unbalanced 336 ACSR	10
Edit	Line.L3	3X_397AS_2ASN 3X_397AS_2CUN	10
Edit	Line.L4		10

Feeder Simulator

- Voltage Regulation
  - Does Voltage Stay Within ANSI Limits?
  - Do More Tap Changes & Cap Bank Switchings Occur?
- Overcurrent Protection
  - Do the Devices Still Coordinate?
- Flicker Calculation, like the Quick Version plus:
  - Determines the Actual Feeder Source Strength
  - Allows Multiple Turbine Locations
- MultiSpeak Importer (others to be added)

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Milsoft's WindMil Product

- Has the dominant market position for engineering analysis (EA) software in rural electric cooperatives
- See www.milsoft.com for product specifications and pricing
- If a cooperative has electrical feeder data, it's most likely in WindMil
- (Aspen's DistriView will also be supported)

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MultiSpeak Initiative

- Specification for exchange of Data and Messages among software applications
- Focused on small electric utilities (contrast to the IEC Common Information Model, www.cimusers.org)
- Major support from NRECA Cooperative Research Network
- Web technologies (XML files, SOAP, TCP/IP socket streaming)
- Version 2.0 Released (www.multispeak.org)
- WindMil supports MultiSpeak

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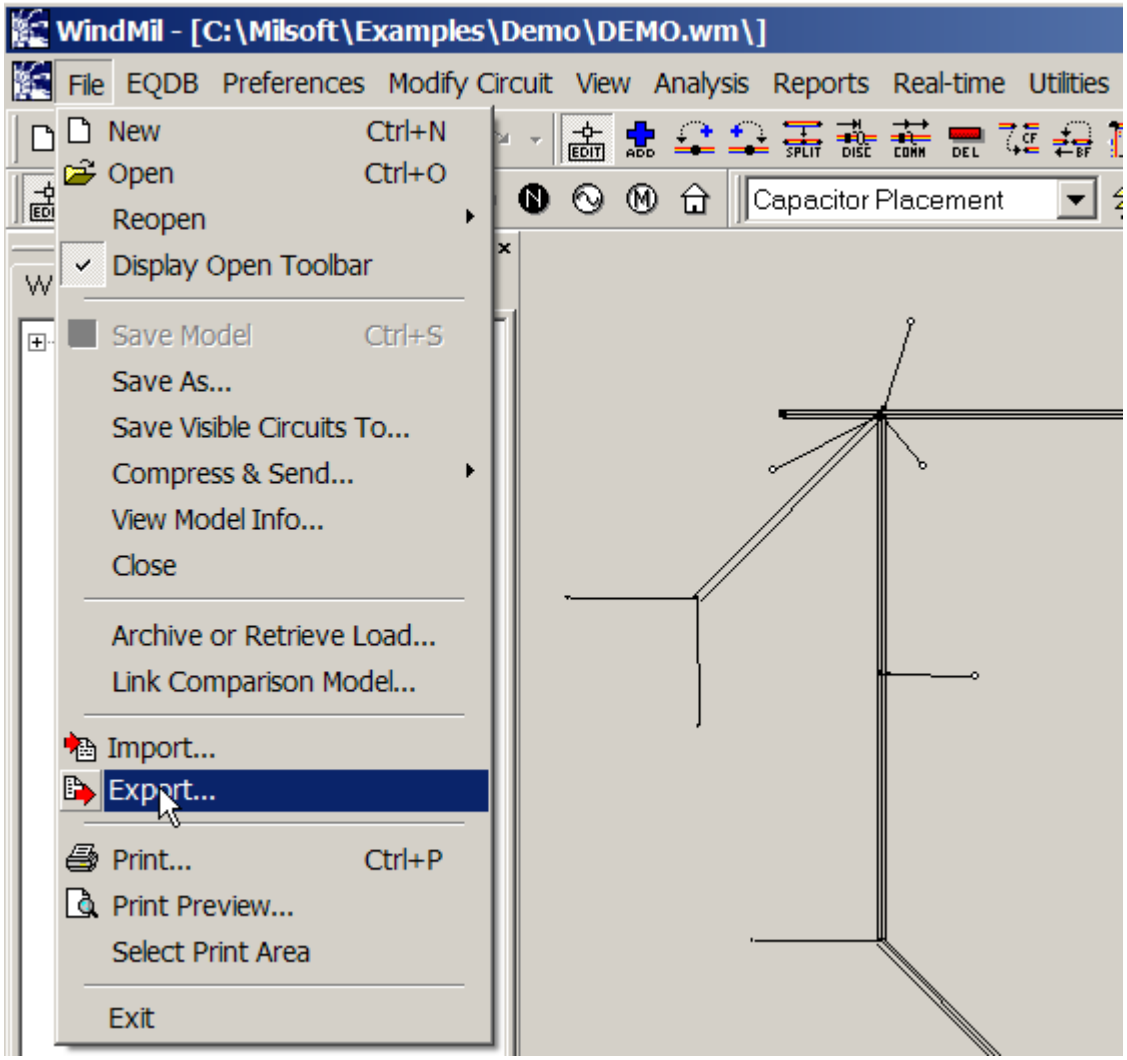
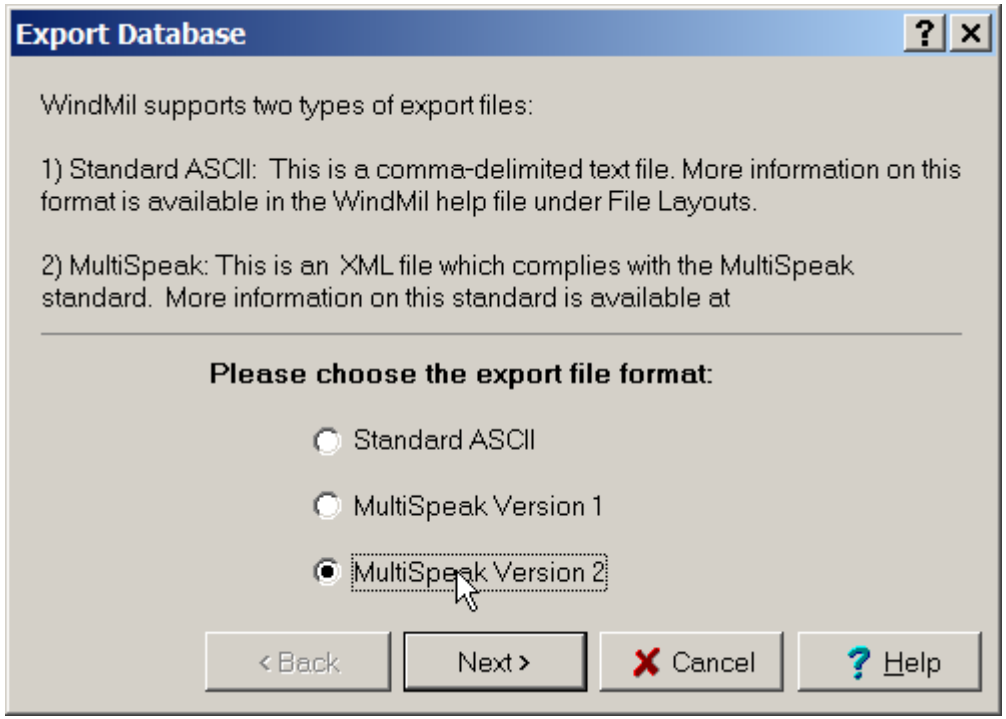
WindMil Export - 1



WindMil Export - 2



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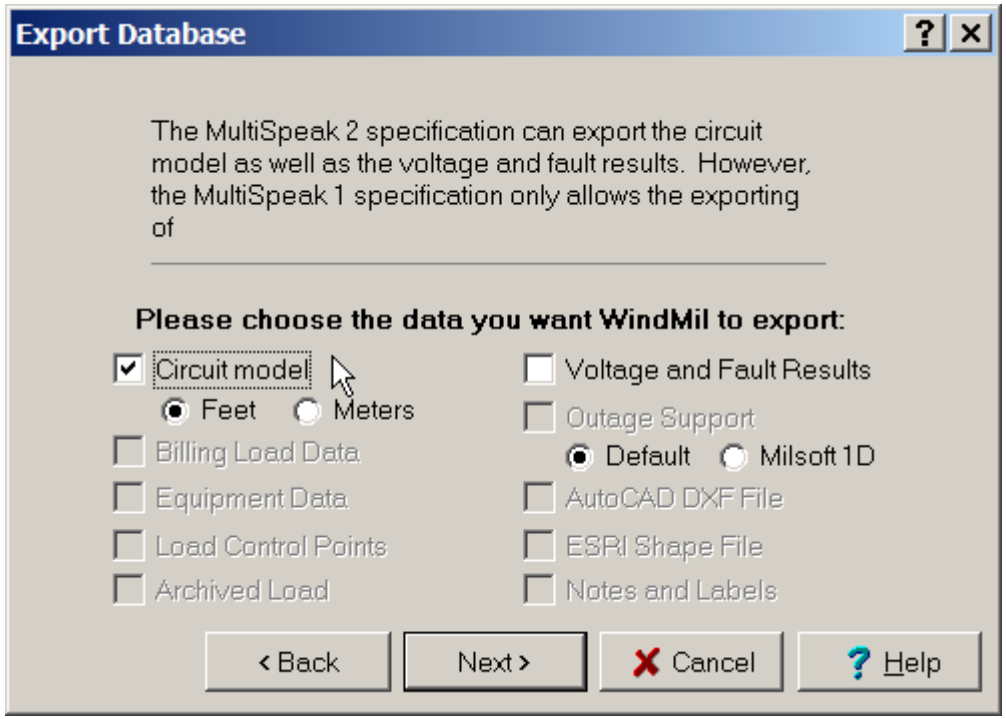
WindMil Export - 3



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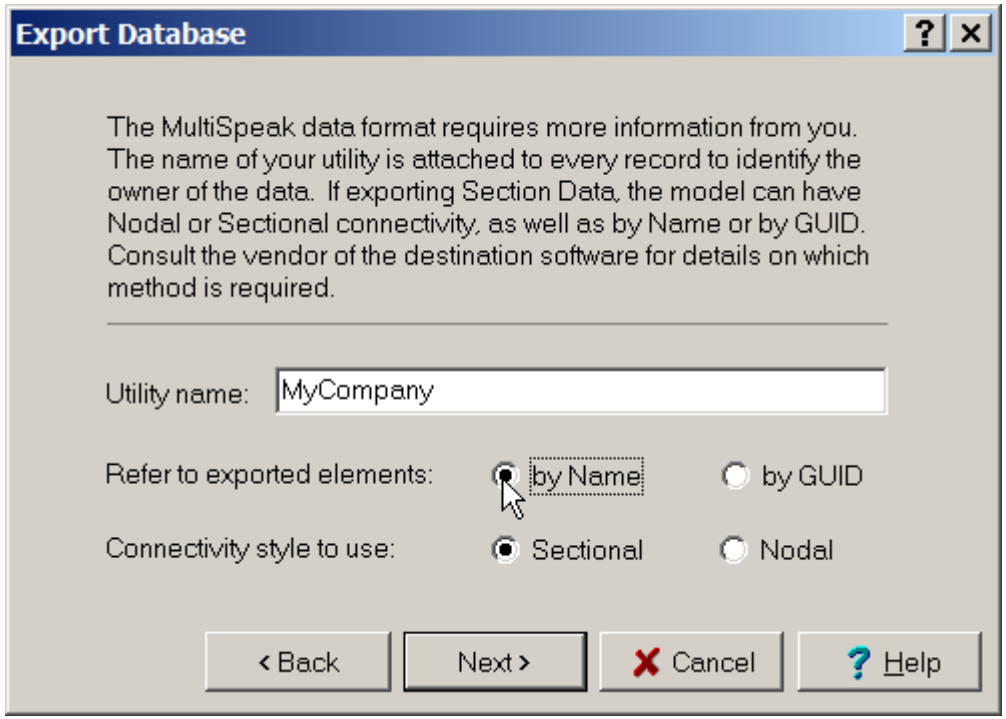
WindMil Export - 4



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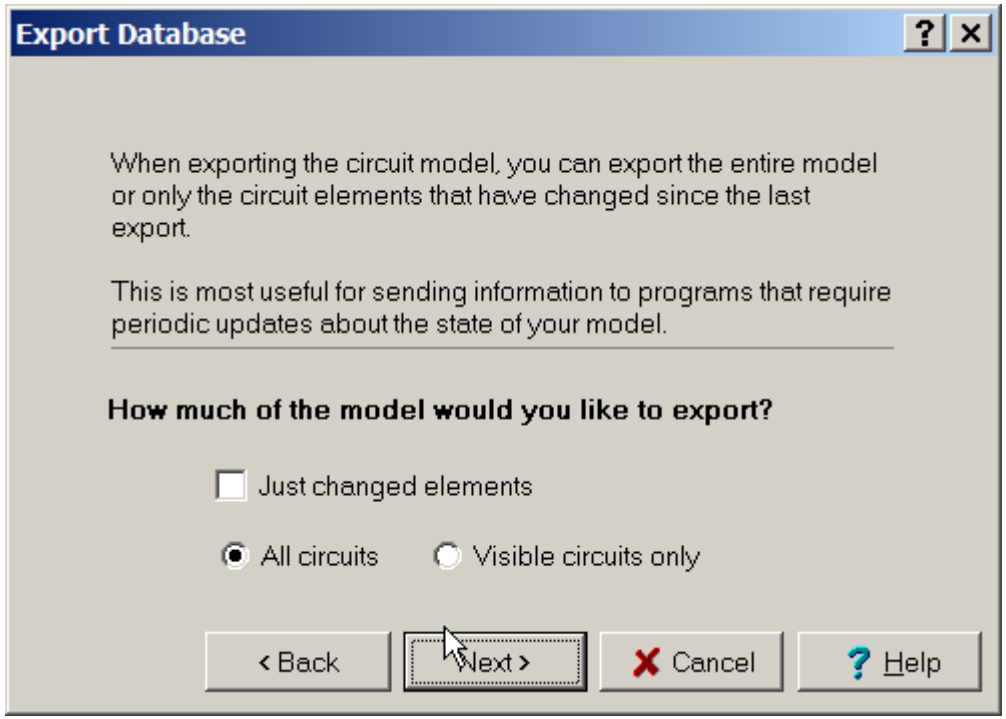
WindMil Export - 5



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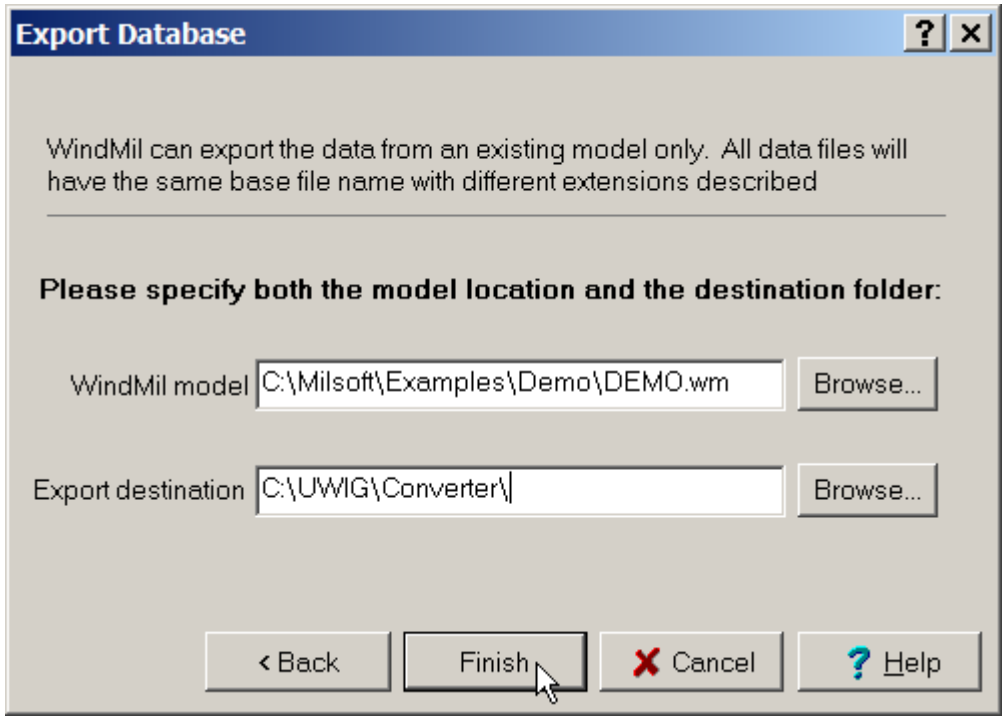
WindMil Export - 6



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MultiSpeak Importer

Import/Export

Upload Circuit | C:\uwig\converter\nreca.xml | Browse...

Import Multispeak

Save Circuit

Import/Export

Continue

Cancel

Select a Feeder Endpoint for WindGen1:

Line.23843, kw=305.7, kvar=117.1, kft=10.1, devices=Fuse.23663,Recloser.23552,Recloser.BALDW1,
Line.23529, kw=195.2, kvar=76.1, kft=14.6, devices=Fuse.23673,Recloser.23665,Recloser.BALDW1,
Line.23697, kw=143.9, kvar=58.7, kft=6.7, devices=Recloser.BALDW1,
Line.23857, kw=175.0, kvar=76.6, kft=17.2, devices=Recloser.23552,Recloser.BALDW1,
Line.23839, kw=189.6, kvar=76.6, kft=9.6, devices=Fuse.23661,Recloser.23552,Recloser.BALDW1,

Total kft = 62.8
Total kW = 3687.0
Total kVAR = 3112.8

Loads

	ID	kW	pf	kV
Edit	Load.LD0	2666.557	0.7639895	13.19823
Edit	Load.LD1	601.7995	0.7799069	13.19823
Edit	Load.LD2	33.16794	0.7331907	13.19823
Edit	Load.LD3	370.0412	0.7443997	13.19823
Edit	Load.LD4	15.4152	0.7147698	13.19823

- Export WindMil➔ MultiSpeak
- Upload MultiSpeak XML
- Choose the Branch for WTG
- That Branch is Fit Into the One-line
- User Must Provide Overcurrent Settings
- Need More Test Files!!

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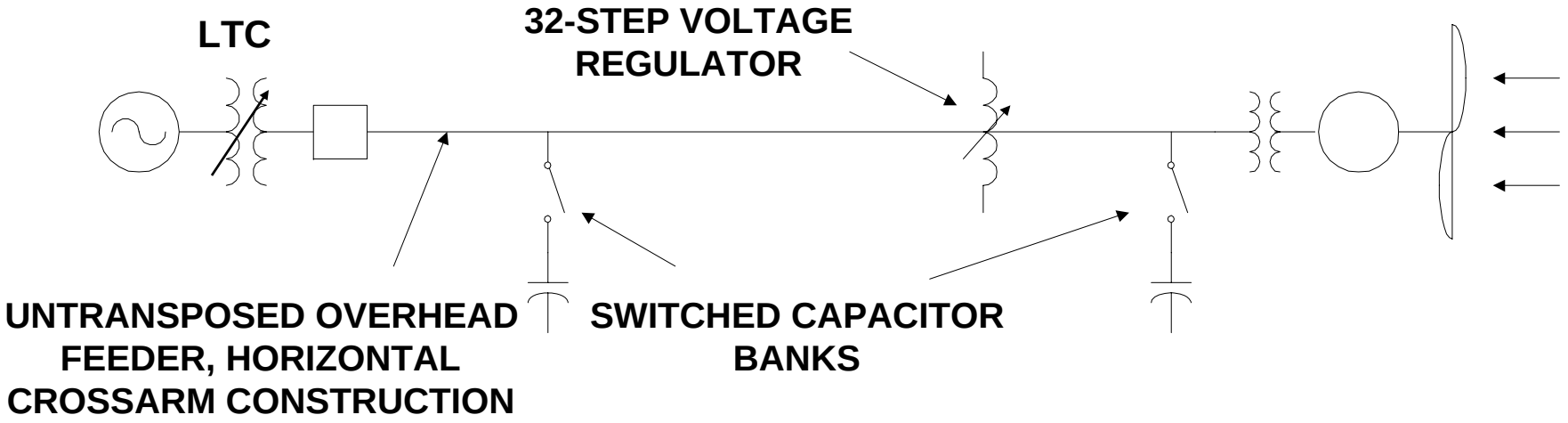
Feeder Voltage Regulation



- DG Constitutes Another Source, May Reverse Power Flows
- Special Wind Concern: Excessive Tap Changes and Capacitor Bank Switching Operations?

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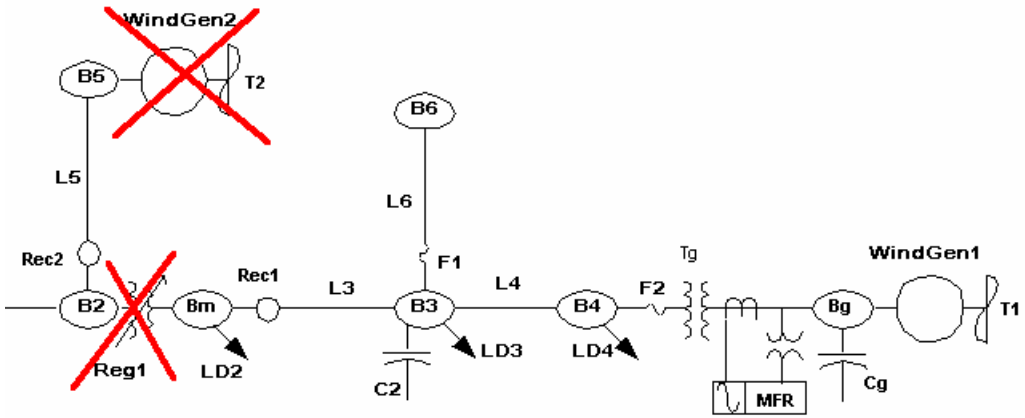
Wind Compensation Example



Generators

	ID	Use	kV	Nom kVA	Max kW	Conn	Model	kVAR	pf	Wind Profile
Edit	Generator.WindGen1	True	0.48	4000	4000	UngroundedWye	FixedReactance	-2479	0.8499979	Wind2400
Edit	Generator.WindGen2	False	12.47	10000	8000	UngroundedWye	ConstantPF	0	1	Wind2400

Solve

Voltage Profile	Step [s]: 1 N steps: 2400 Amin[pu]: 0.975 Amax[pu]: 1.05 Bmin[pu]: 0.95 Bmax[pu]: 1.058
Flicker	
Fault Analysis	Step [s]: 0.01667 N steps: 940

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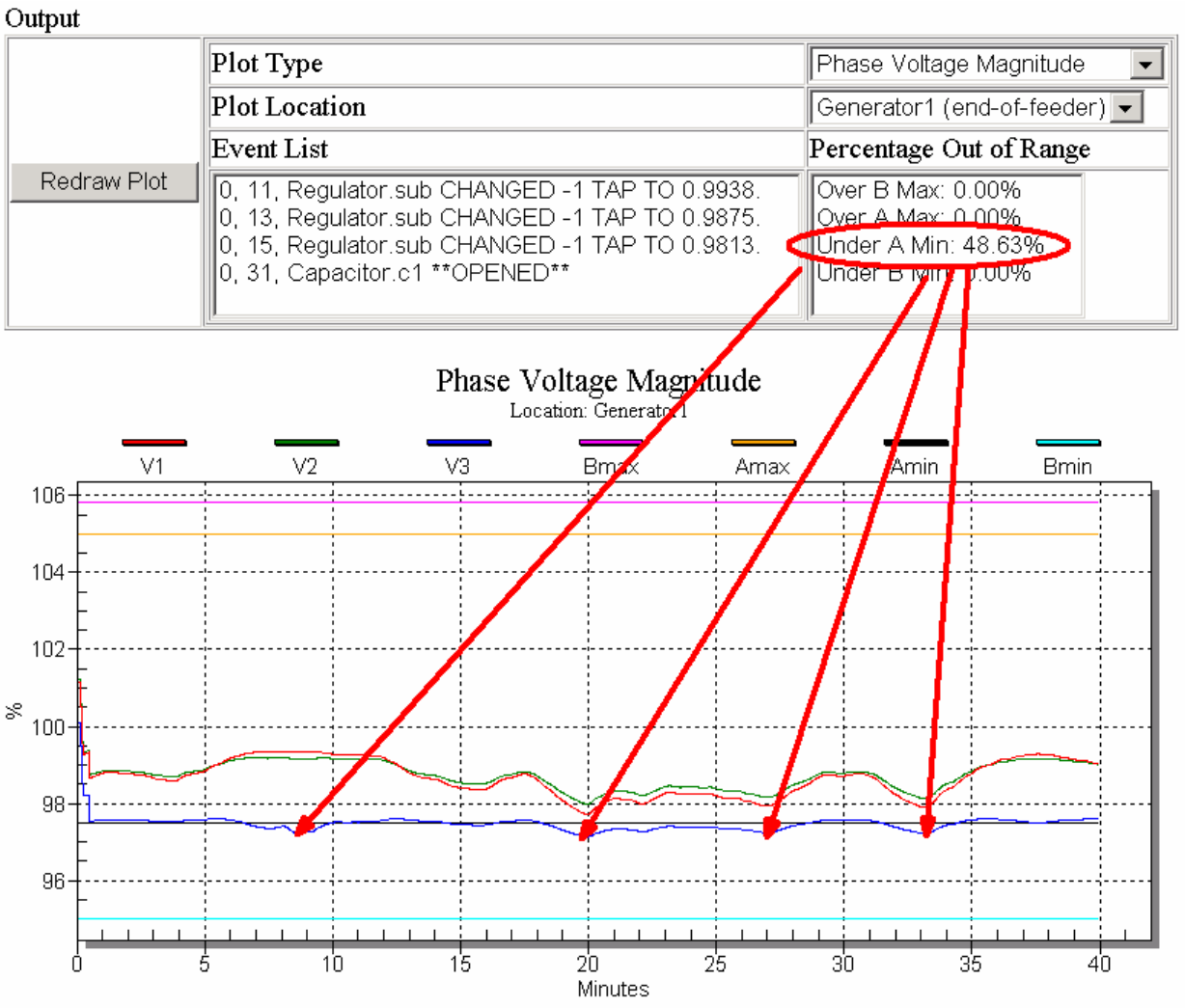
Voltage Profile Results

- Low Voltage at End of Feeder Due to VAR Consumption
- Event List shows Tap Changes and Switching Operations
- Can Also Plot Unbalance, Tap Changes, Phase Current, and Sequence Voltage



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Overcurrent Protection

Edit

- Capacitors
- Fault
- Generators
- Lines
- Loads
- Regulators
- (•) Set: Fuses

Set: Fuses

	ID	Use	Amps	Curve
Edit	Fuse.F1	True	65	klink
Edit	Fuse.F2	True	65	tlink

Set: MFR 46 Negative Sequence I

	ID	Use	Amps Base	Pct Pickup	Isq T	Delay
Edit	Relay.MFR46	True	1800	20	1	0.1

Set: MFR 47 Negative Seq. V

	ID	Use	kV Base	Pct Pickup	Delay
Edit	Relay.MFR47	True	0.48	2	0.1

Set: MFR OV/UV per IEEE 1547

	ID	kV	Use OV	OV Curve	Use UV	UV Curve	Delay
Edit	Relay.MFROV/UV	0.48	True	ov1547	True	uv1547	0

Edit

- Capacitors
- Fault
- Generators
- Lines
- Loads
- Regulators
- Set: Fuses
- Set: Ground Trip
- Set: MFR 46
- Set: MFR 47
- Set: MFR OV/UV
- (•) Set: Phase Trip

Set: P

	ID	Use Delay	Delay Trip	Fast Curve	Slow Curve
Edit	Relay.CB1	True	800	d	d
Edit	Relay.CB2	True	800	d	d
Edit	Relay.MFR50/51	True	8000	d	d
Edit	Recloser.Rec1	True	280	a	d
Edit	Recloser.Rec2	True	200	a	d

- Lots of Data!
- Separate Phase and Ground settings
- Multifunction relay at the WTG

MFR Settings per IEEE 1547

- Undervoltage
  - 0.16s if voltage < 50%, 2s if voltage 50% to 88%
- Overvoltage
  - 0.16s if voltage > 120%, 1s if voltage 110% to 120%
- Negative Sequence V and I are Optional Backups
  - Often used for generator protection
- Frequency Settings (not in the Feeder Simulator)
  - 0.16s if frequency > 60.5 or < 57.0
  - 0.16s to 300s if frequency 57.0 to 59.8

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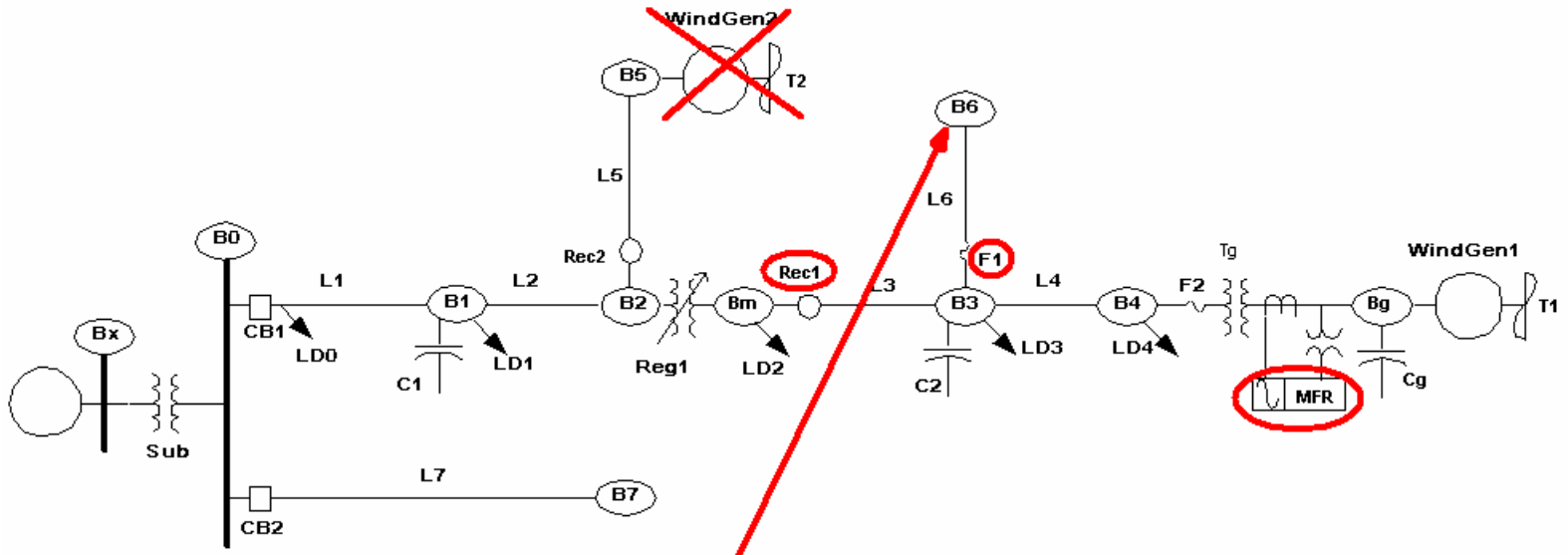
Temporary SLGF on a Lateral



Edit

- Capacitors
- Fault
- Generators

Fault

	ID	Use	Location	Type	Clearing	R	Time
Edit	Fault.TheFault	True	B6	SingleLineToGround	Temporary	0.0001	1

Solve

Voltage Profile	Step [s]: 1	N steps: 720
Flicker		
Fault Analysis	Step [s]: 0.01667	N steps: 260

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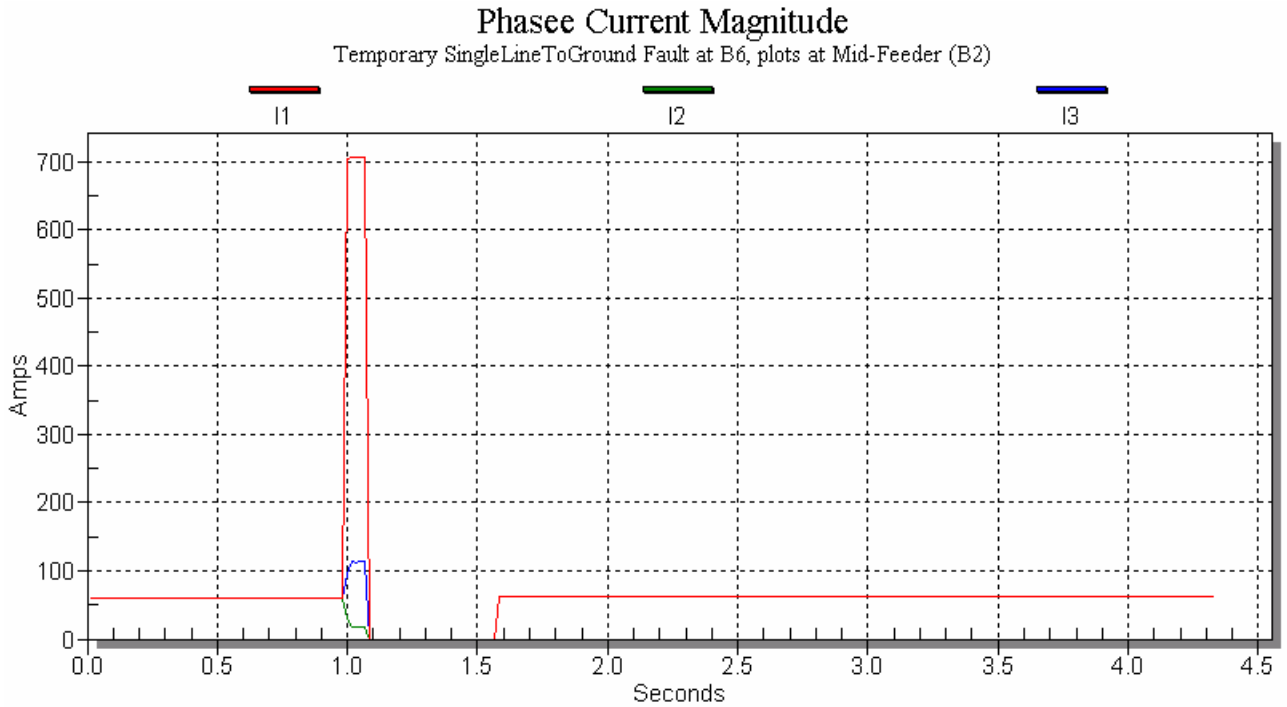
Fast Trip and Reclose

Event List

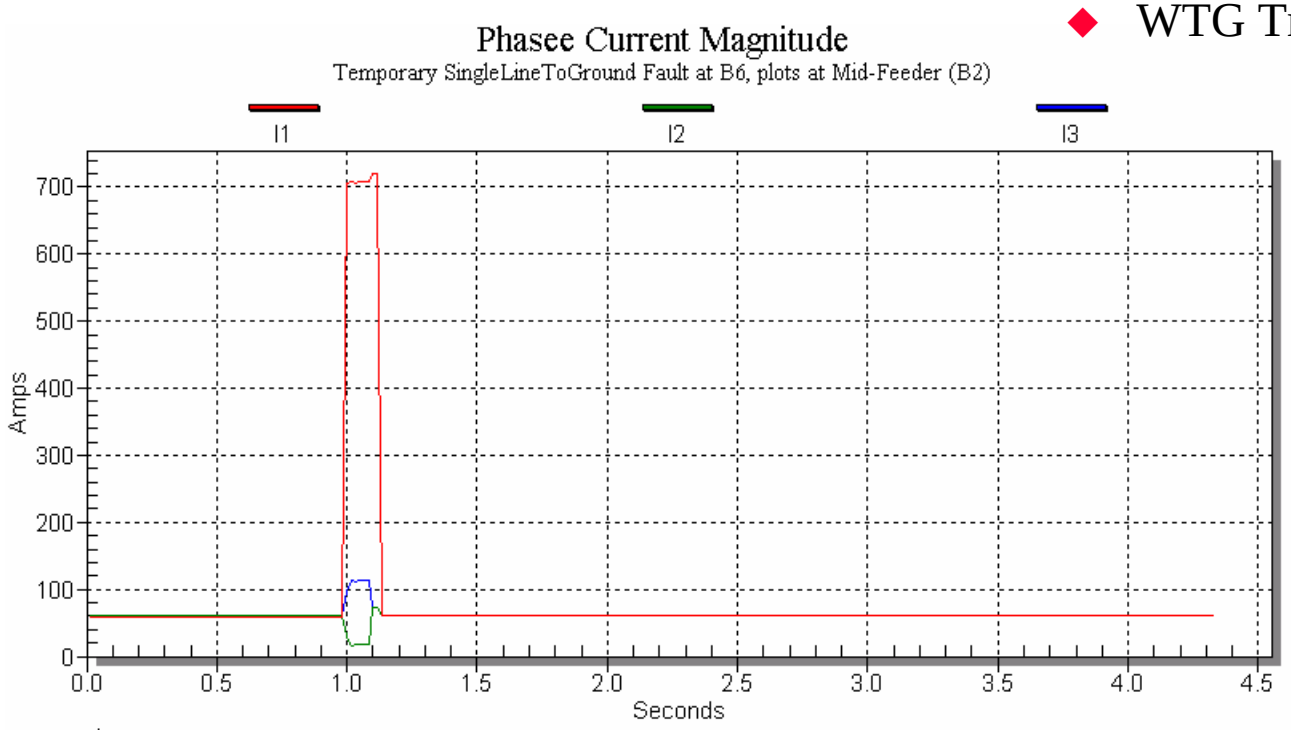
0, 1.0835, Recloser.rec1 OPENED, FAST
0, 1.0835, PHASE TARGET
0, 1.0835, Fault.thefault **CLEARED**
0, 1.1669, Relay.mfrov/uv OPENED ON UV & LOCKED OUT
0, 1.5836, Recloser.rec1 CLOSED

- Fault Clears after Fast Trip
- WTG Trips on Lost Voltage
- Reclose is Successful



Remove the Fast Trip

Event List	
	0, 1.1002, Relay.mfr47 OPENED ON -SEQ V & LOCKED OUT 0, 1.1002, Relay.mfr46 OPENED ON -SEQ CURR & LOCKED OUT 0, 1.1336, Fuse.f1 PHASE 1 BLOWN 0, 1.1336, Fault.thefault **CLEARED** 0, 1.1669, Relay.mfrov/uv OPENED ON UV & LOCKED OUT

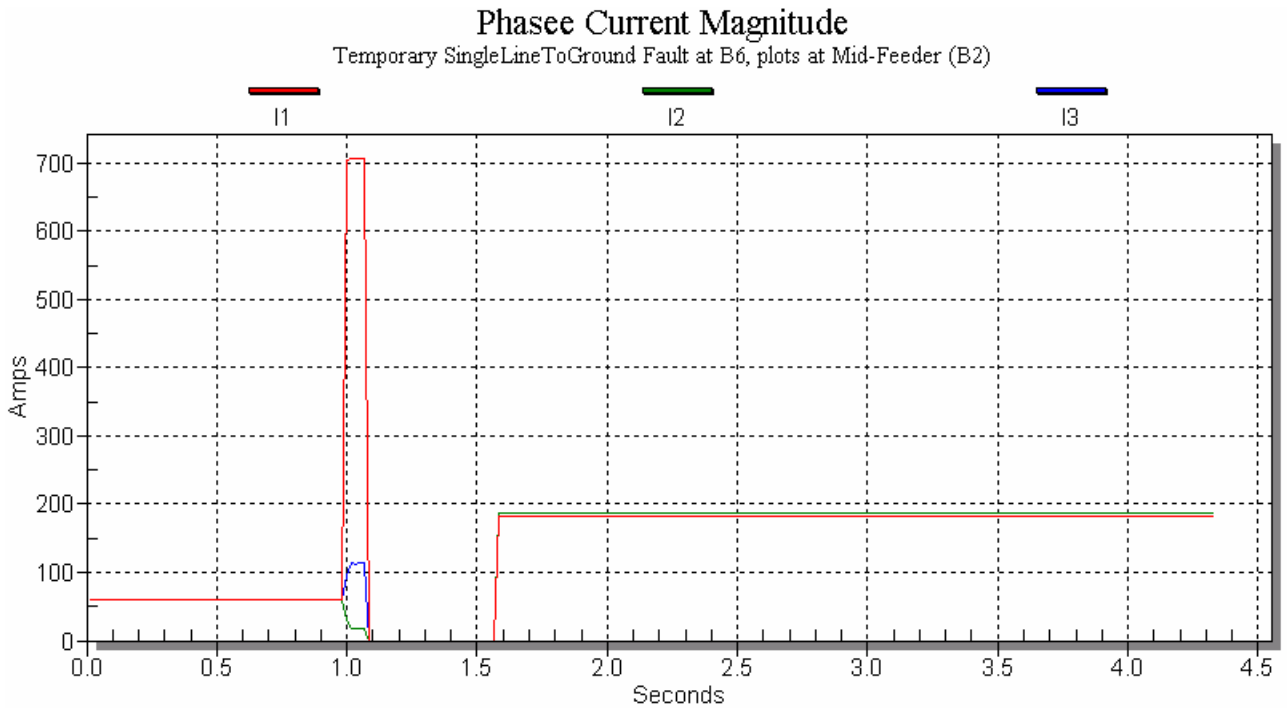


- Fuse Clears the Fault
- No Loss of Voltage at the WTG, but
- WTG Trips on Unbalance

Restore Fast Trip, De-sensitive MFR

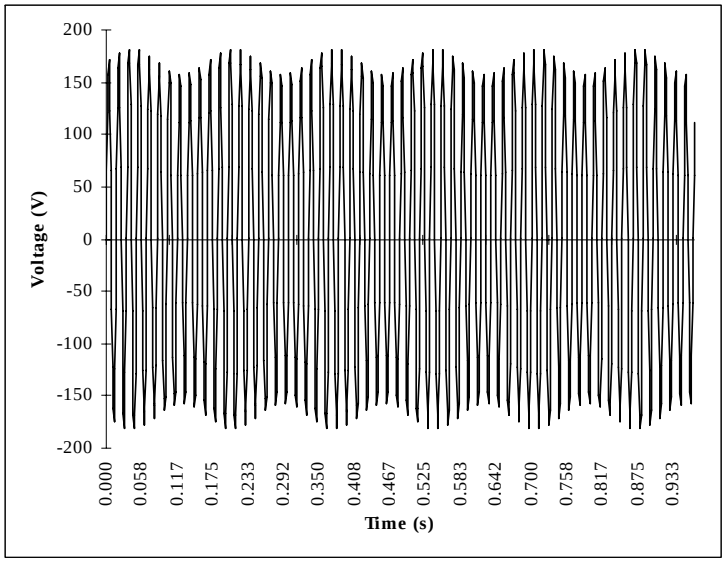
Event List	
	0, 1.0002, Fault.thefault **APPLIED**
	0, 1.0835, Recloser.rec1 OPENED, FAST
	0, 1.0835, PHASE TARGET
	0, 1.0835, Fault.thefault **CLEARED**
	0, 1.5836, Recloser.rec1 CLOSED

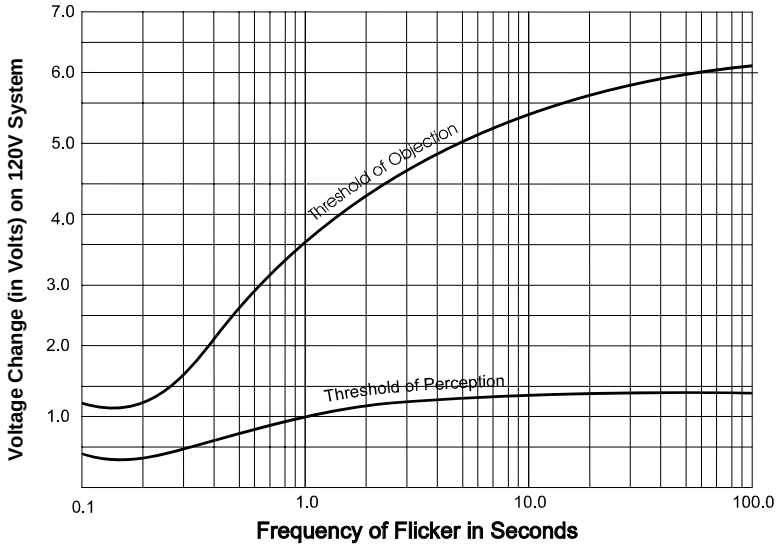
- WTG Never Trips
- High Current After the Reclose



What is Flicker?

- Short-term Voltage Fluctuations that may cause perceptible, or objectionable, lighting flicker





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What Causes Flicker?

- Motor starting and load variations
- Arc furnaces and welders
- Wind turbines
  - Variations in wind speed
  - Blade pitching
  - Tower shadowing
  - Wind shear or gradient
  - Start and stop

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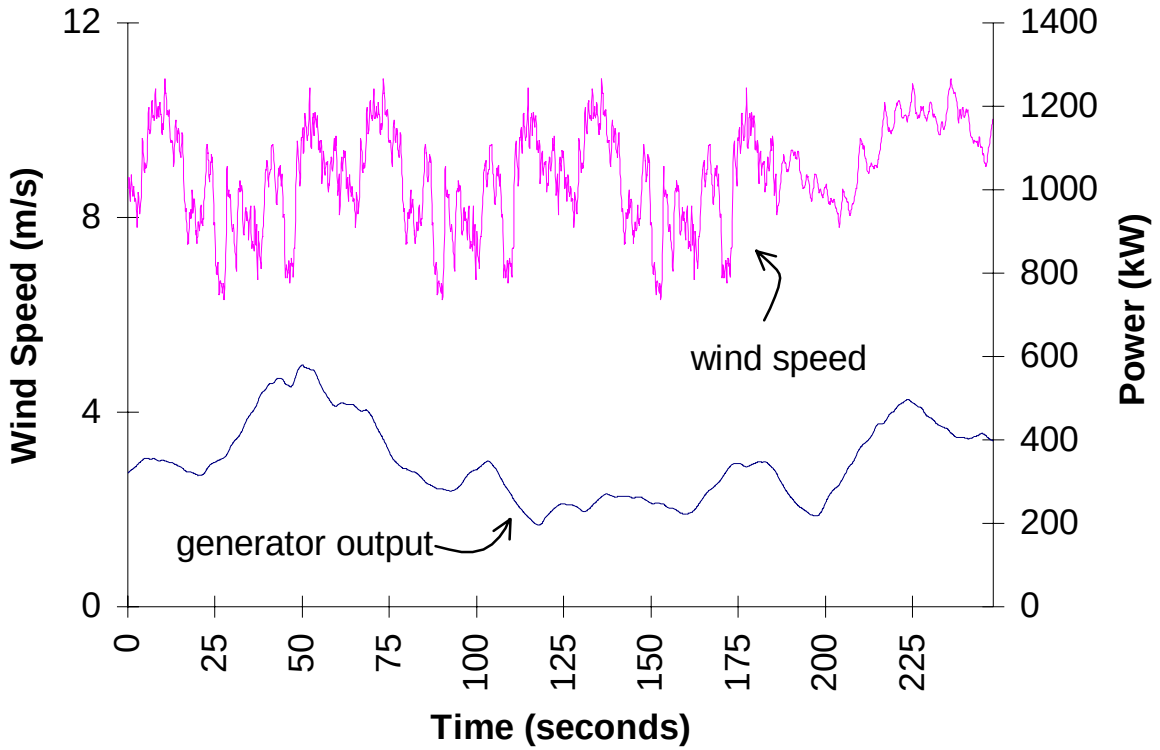
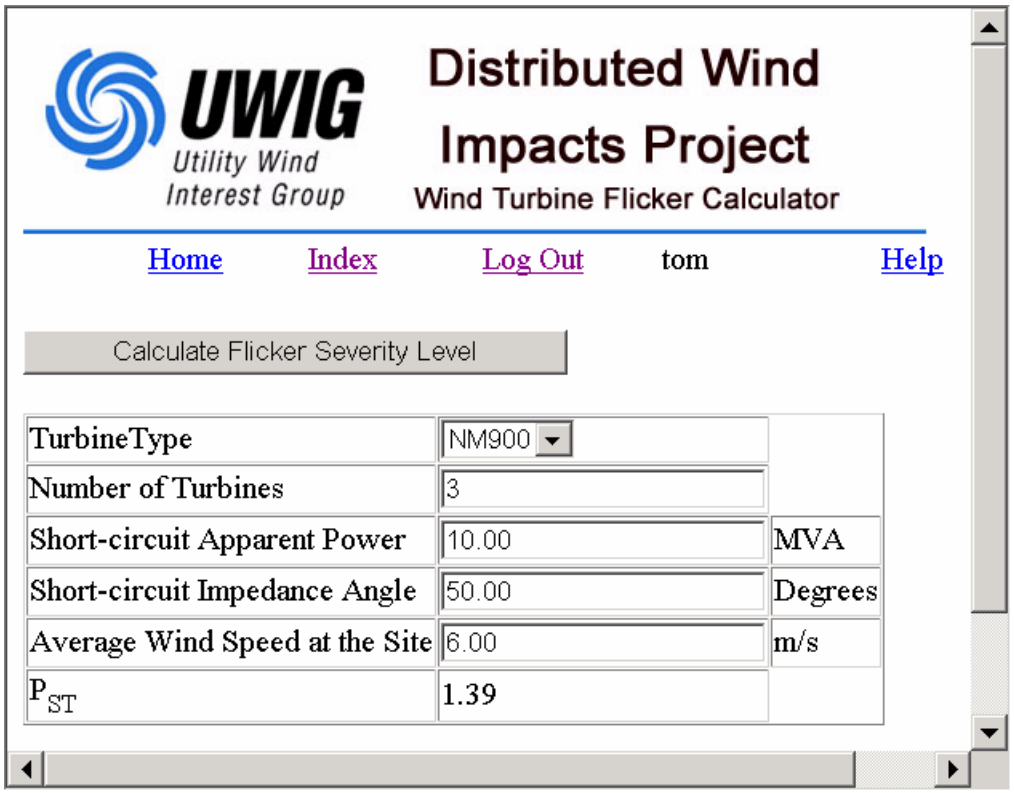
Variations in Wind Speed

- Inertia and controls help soften the impact



Flicker Calculator



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Economic Screening Applet

- Based on NREL's WindFinance
  - http://analysis.nrel.gov/windfinance/login.asp
- UWIG Added:
  - Power Curve download for the Feeder Simulator
  - Sensitivity Analysis: 1 output vs. 2 inputs
  - Code for these will be supplied to NREL

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Distributed Wind Economics

- Capacity Factor: Determines energy production
- Tax Incentives: Enhance the cash flow
- Plus the usual considerations
  - Debt and Equity financing
  - Insurance, O&M, tax requirements
  - Evaluate by net present value (NPV), internal rate of return (IRR), payback period, etc.
- Look at Wind as an Energy Source, not Capacity

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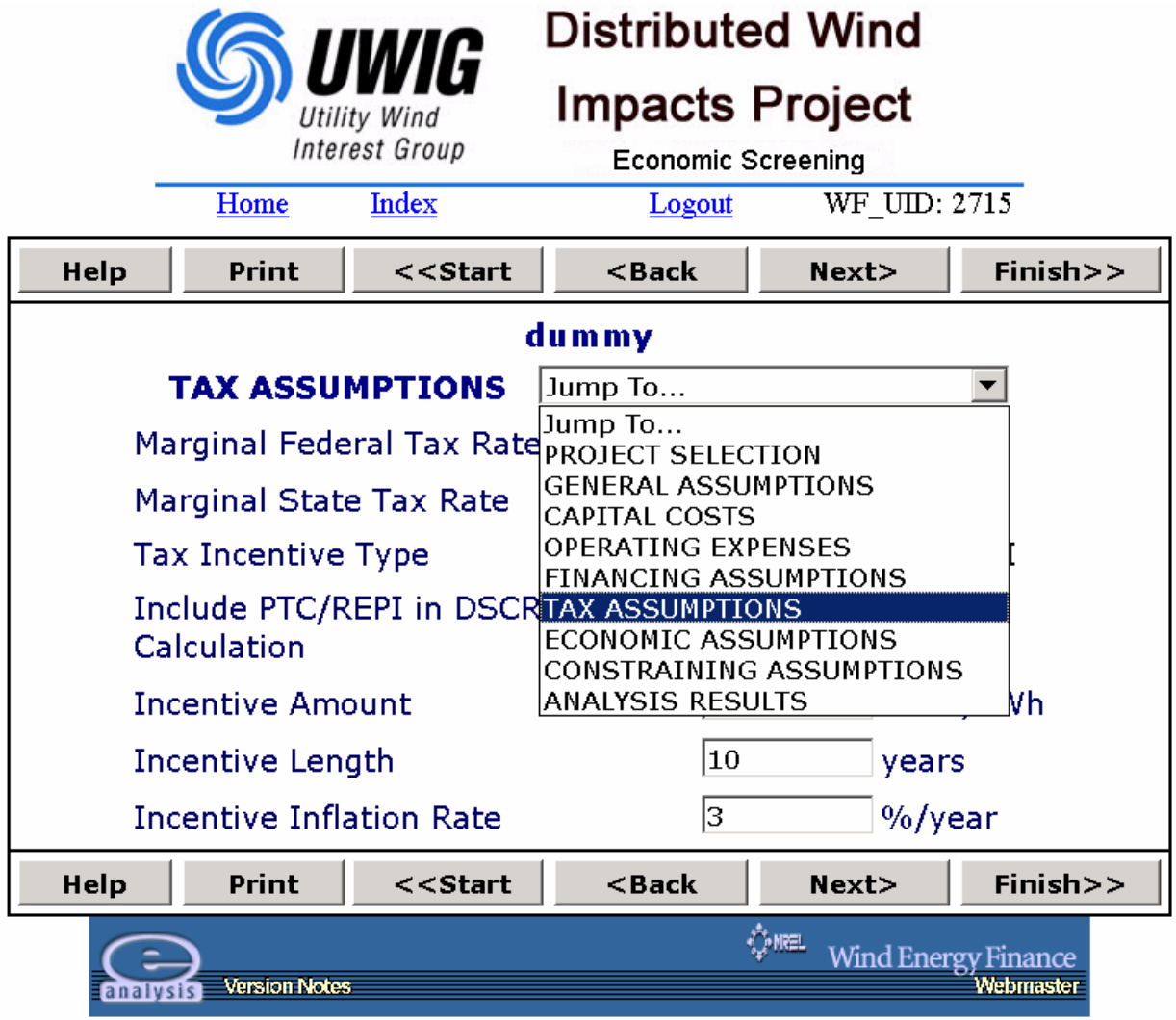
Economics: Base Case

- 7 Input Screens
- Saves Data on the Server



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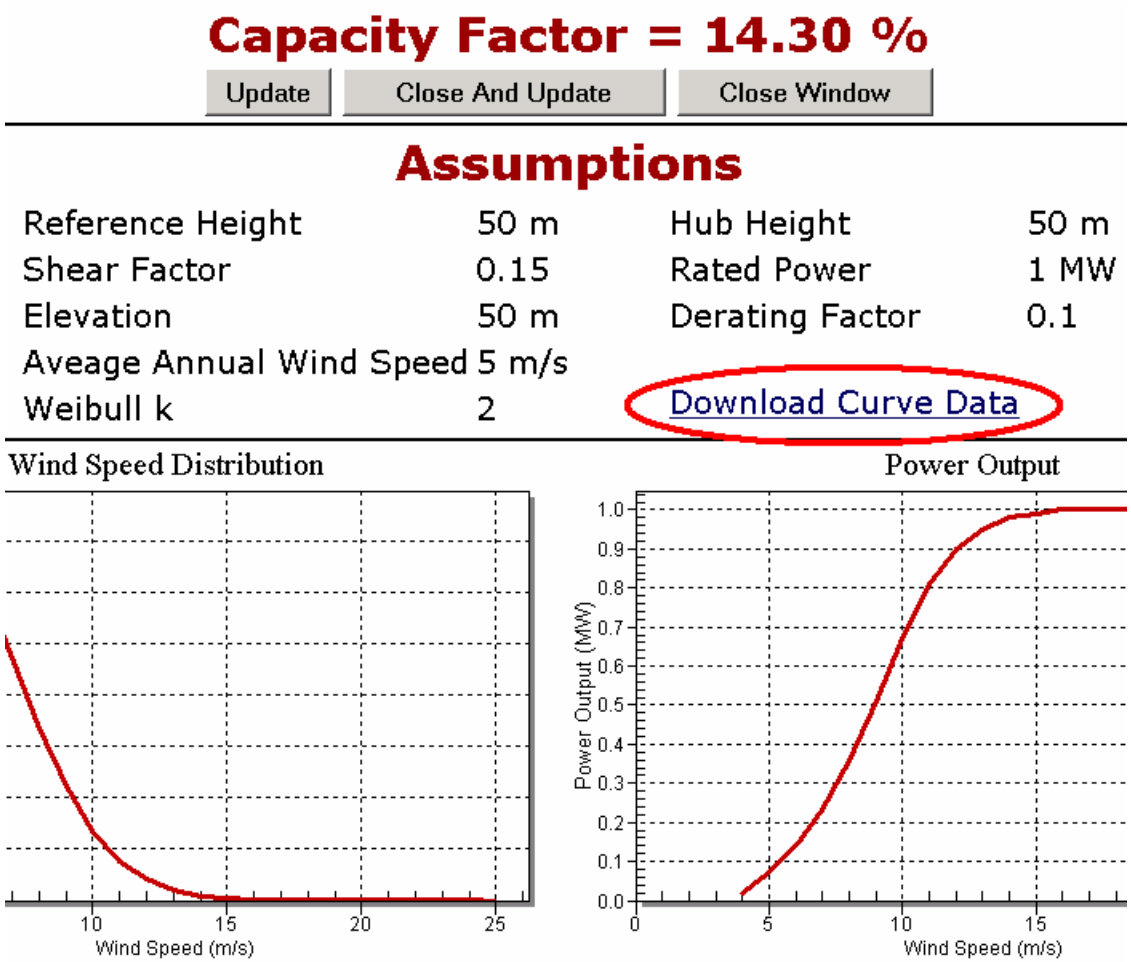
Economics: Capacity Factor Module

- Wind Data:
  - Distribution
  - Average annual speed
  - Grid coordinates
- Power Curve:
  - Specific
  - Generic



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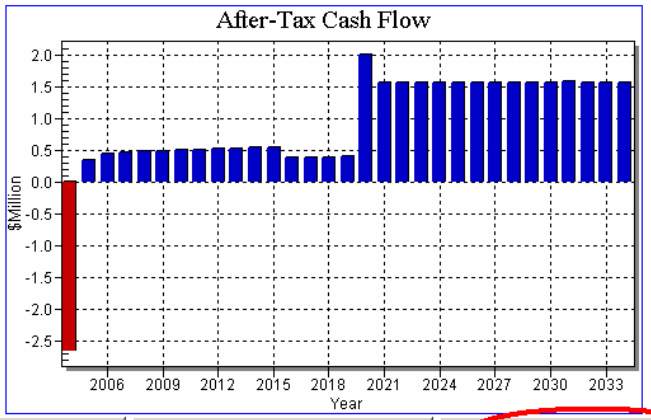
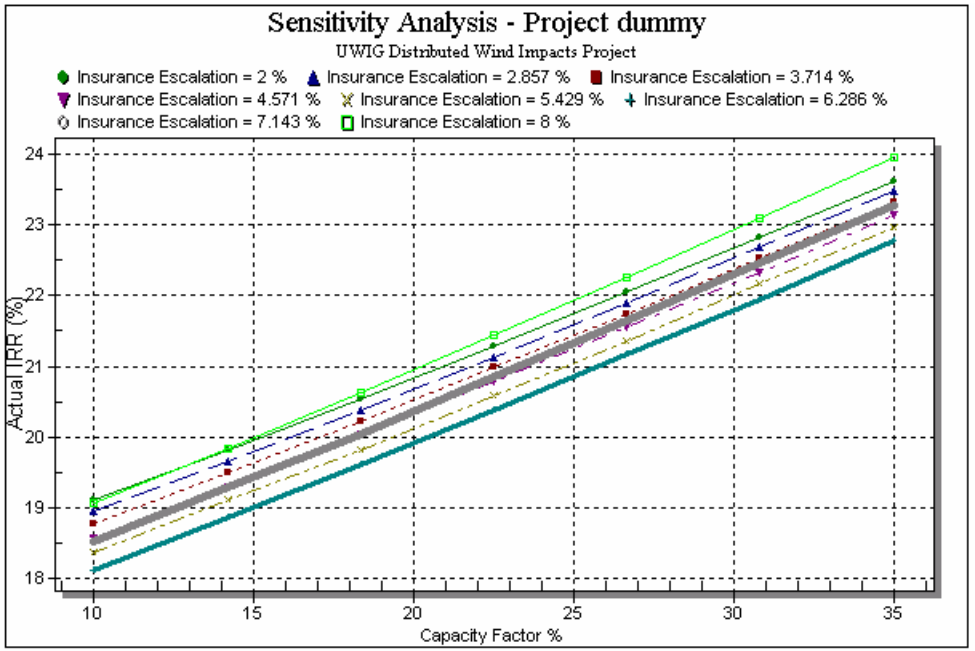
Economics: Sensitivity Analysis





Input quantities: Min Max Steps

Capacity Factor (%)	10	35	6
Insurance Escalation (%)	2	8	7

Output quantity:

Actual IRR (%)

Monitoring Update

Selawik Update

- Remote Alaskan village chosen as the second site
- Site has 4 Atlantic Orient 65 kW turbines and 3 diesel generators
- Power quality monitoring device installed in July, 2005
- Look for measurements on the UWIG web site

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Selawik Location

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Selawik Pictures

Four Atlantic Orient Corp. 65 kW wind turbines installed in the arctic village of Selawik, Alaska.

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Selawik Oneline

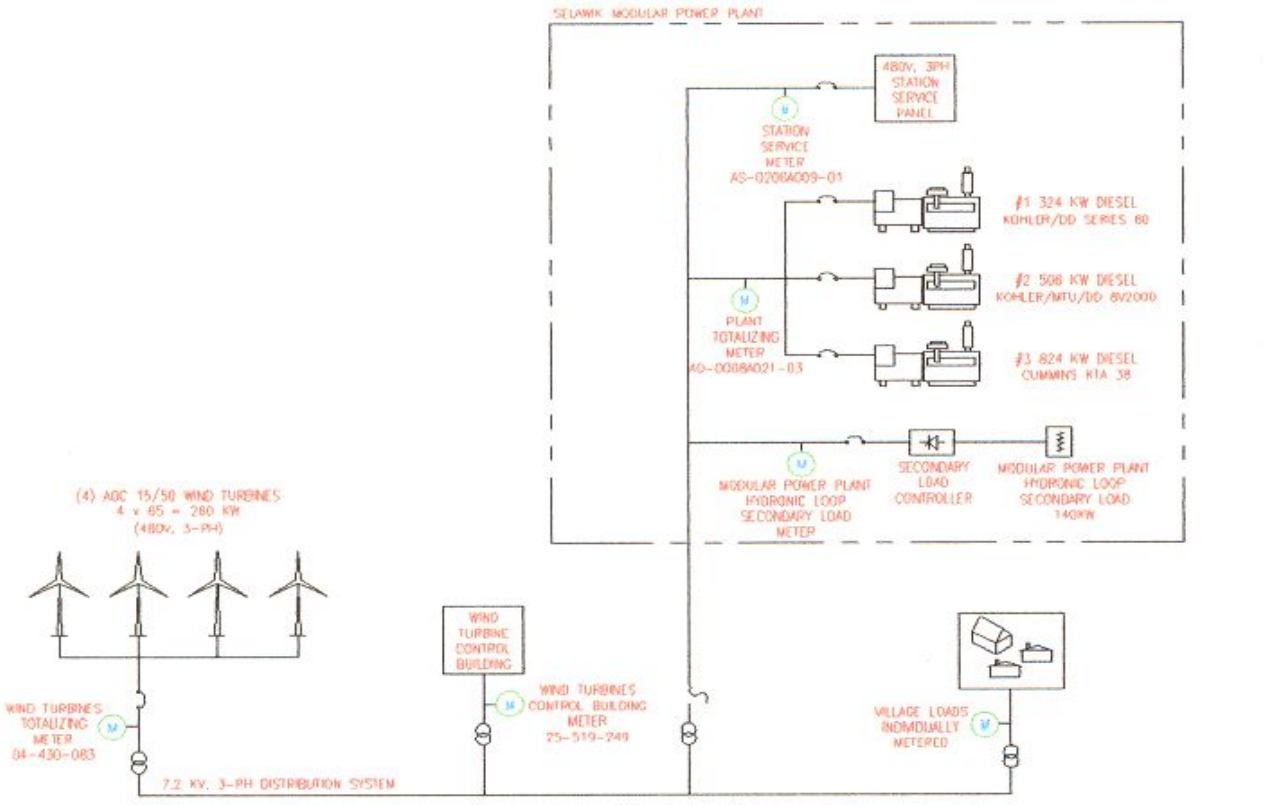
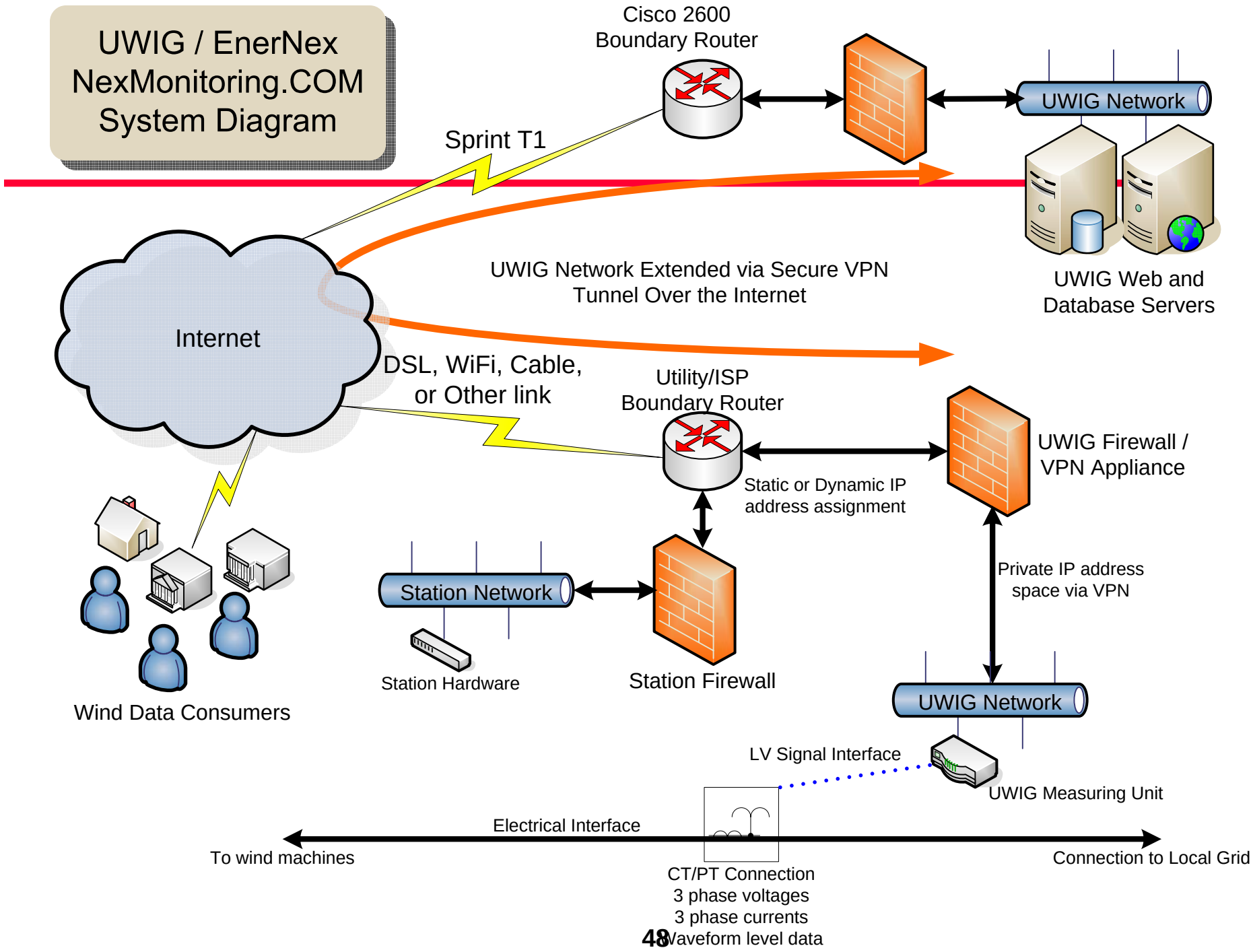


Diagram of the wind-diesel village power system in Selawik, Alaska.

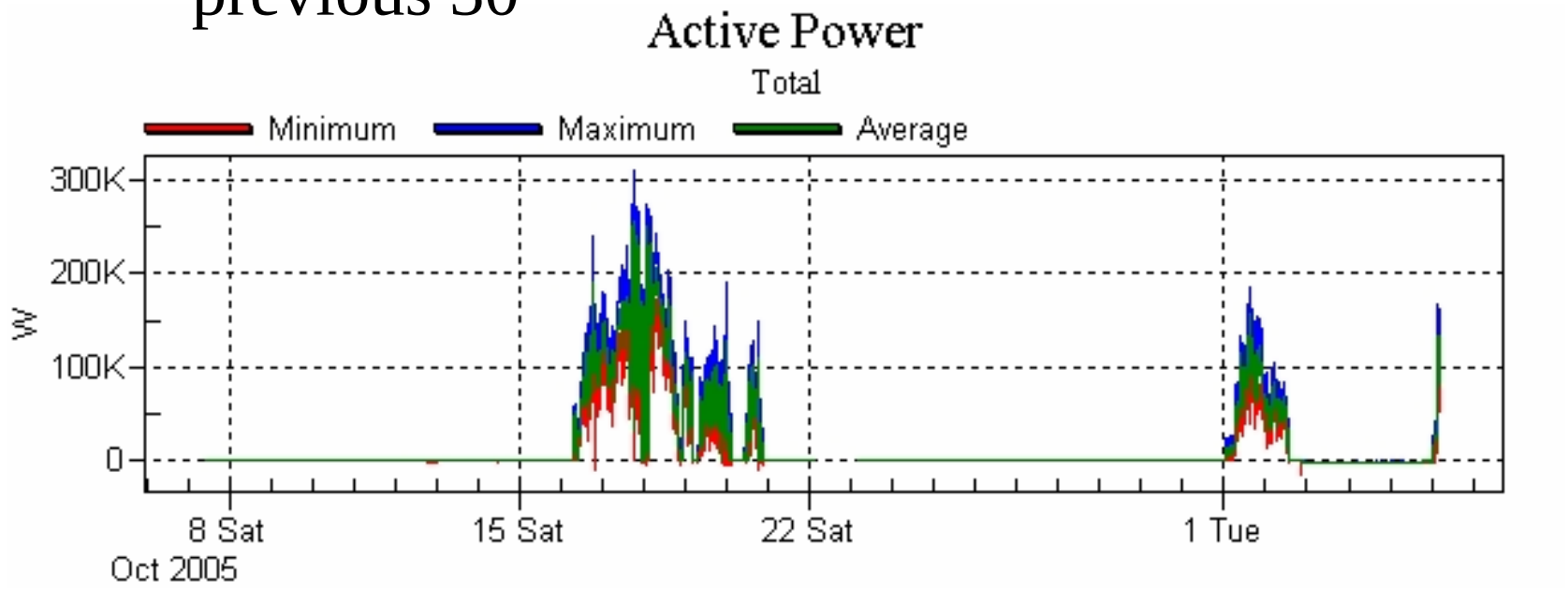
Selawik Monitoring Network

- Challenging Network Connectivity
  - It is in Alaska after all
- Uses multi-hop WiFi link to wired network
- IPSec based VPN router used on each end in addition to firewalls
- Same basic topology used for other monitoring sites (see next slide for diagram)
- Store and forward data gathering method provides immunity to intermittent communications
- Data stored according to IEEE 1159.3 PQDIF
- Events and trends can be visualized using any web browser – even behind a firewall


UWIG / EnerNex
NexMonitoring.COM
System Diagram
Cisco 2600
Boundary Router
UWIG Network
Sprint T1
UWIG Web and
Database Servers
UWIG Network Extended via Secure VPN
Tunnel Over the Internet
Internet
DSL, WiFi, Cable,
or Other link
Utility/ISP
Boundary Router
UWIG Firewall /
VPN Appliance
Static or Dynamic IP
address assignment
Private IP address
space via VPN
Station Network
Station Hardware
Station Firewall
Wind Data Consumers
UWIG Network
LV Signal Interface
UWIG Measuring Unit
Electrical Interface
To wind machines
Connection to Local Grid
CT/PT Connection
3 phase voltages
3 phase currents
Waveform level data

Active Power Output

- Turbines run sporadically, about 7 days over the previous 30



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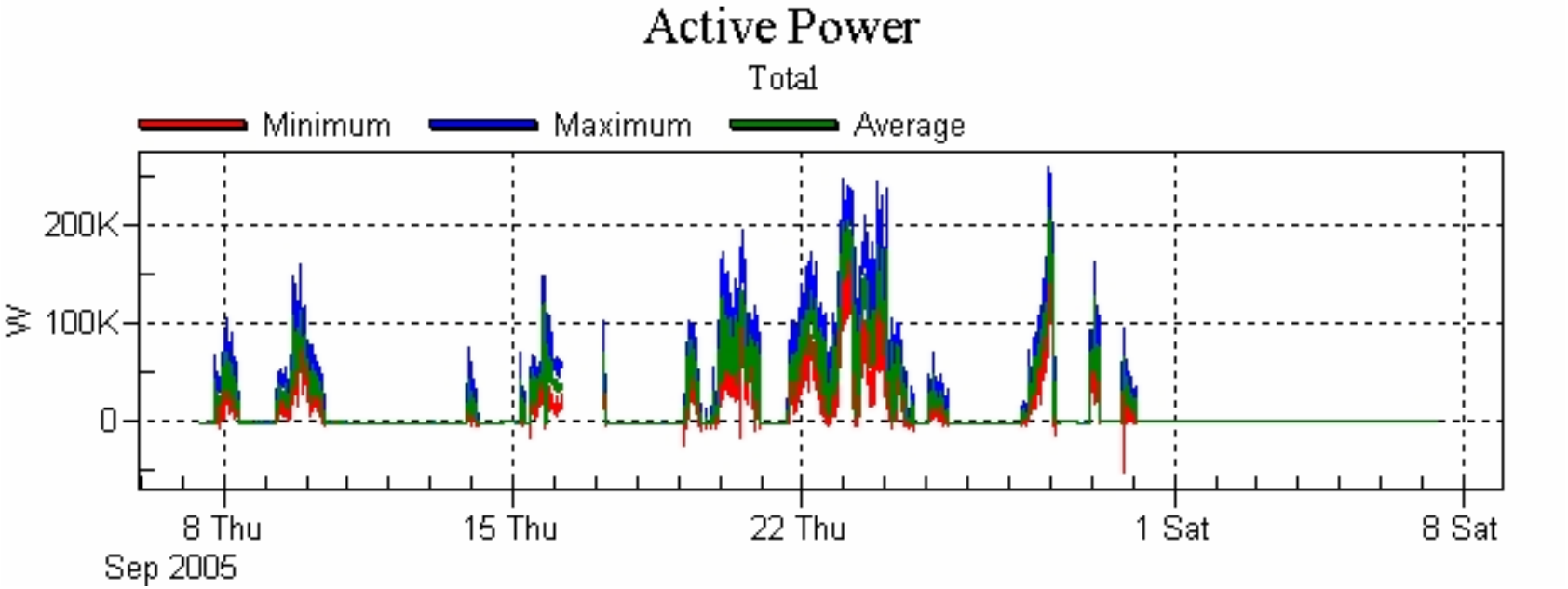
Active Power Output



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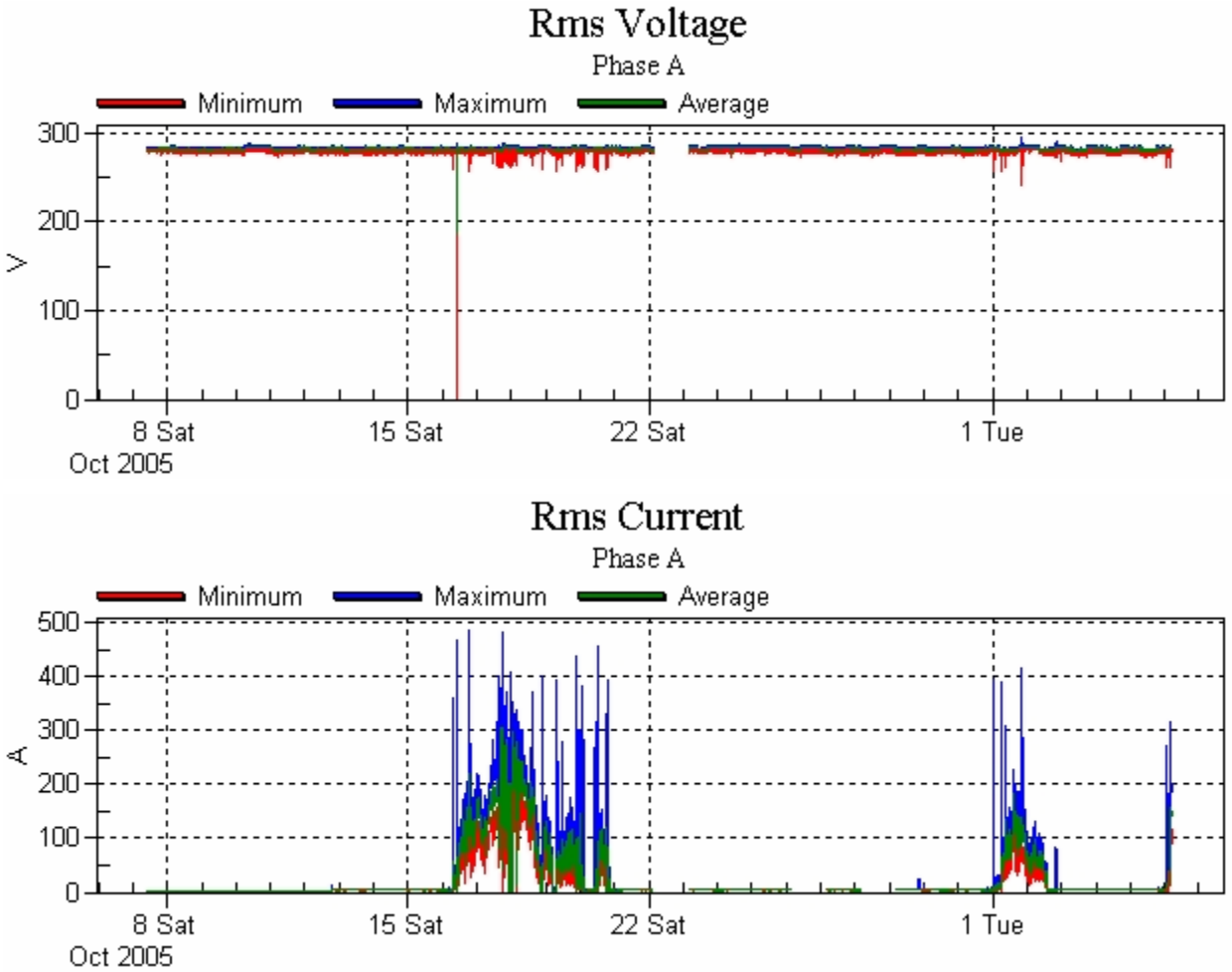
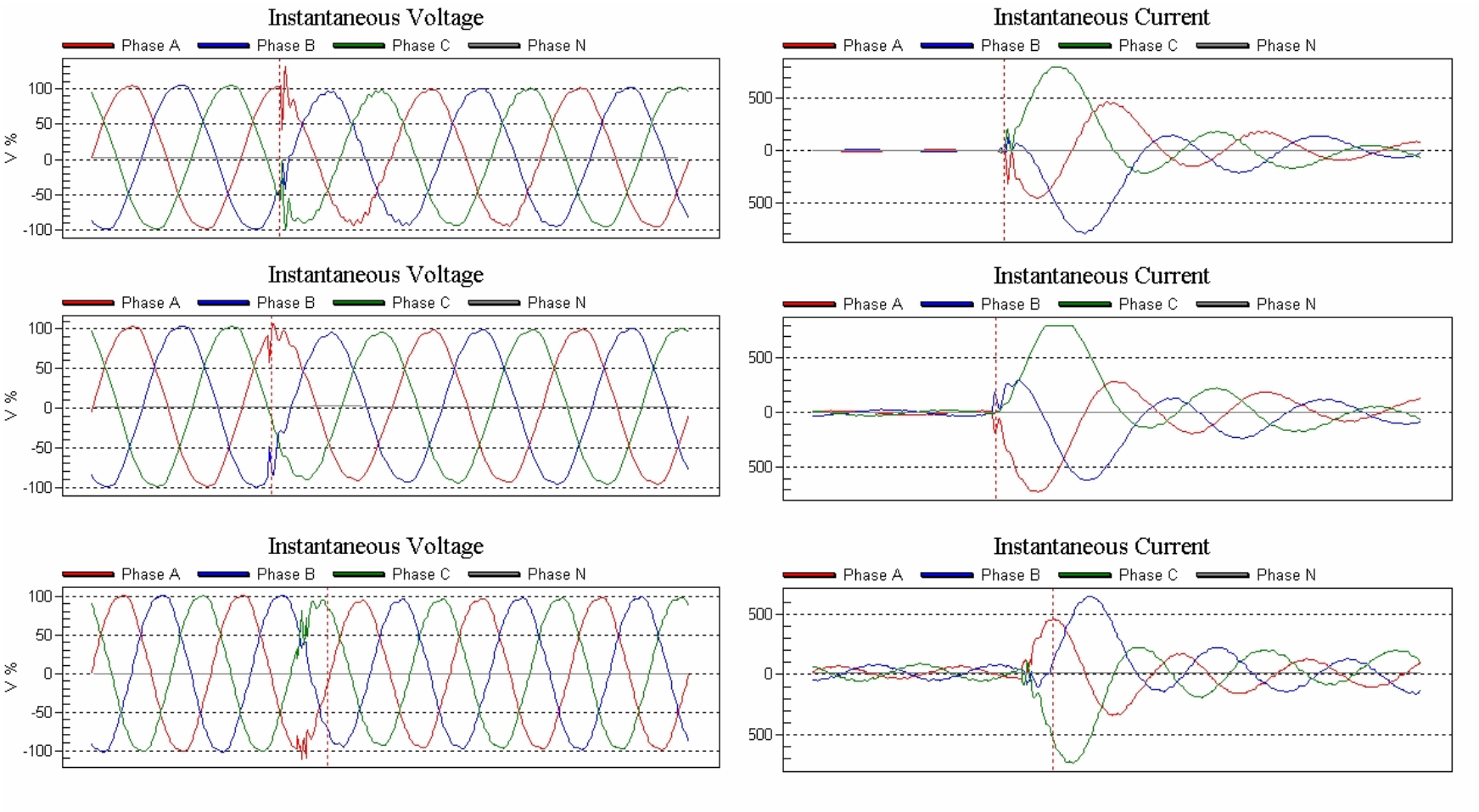
RMS Voltage and Current



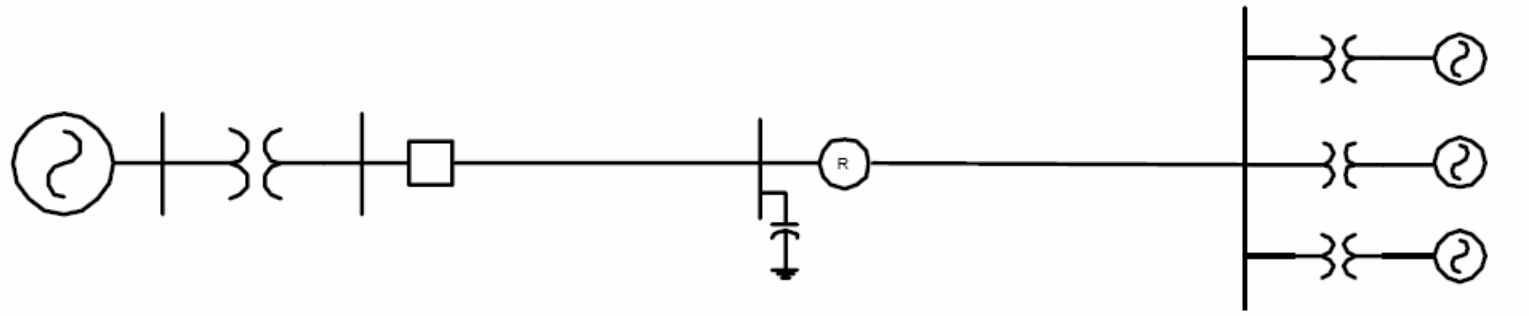
Startup Transients



Distributed Wind Case Studies

TVA: Buffalo Mountain

- Completed in 2004 using custom software
- Re-implement using the present Applets
- Three Vestas V47 WTGs, Total 2 MW
- 13.2-kV Feeder, 9.6 miles long, 69-kV Source



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Buffalo Mountain Data

Turbines

	ID	Type	# Parallel	SC MVA	Z angle	Avg Wind
Edit	Turbine.T1	Vestas V47 / 660	3	12.18	63.07	6

Capacitors

	ID	Use	kVAR	kV	Conn	Control	PT Ratio	V on	V off
Edit	Capacitor.C1	False	600	12.47	GroundedWye	CurrentControl	60	119	125
Edit	Capacitor.C2	True	600	13.2	GroundedWye	VoltageControl	63.5	119	125
Edit	Capacitor.Cg	False	600	0.48	GroundedWye	Fixed	60	0	0

Generators

	ID	Use	kV	Nom kVA	Max kW	Conn	Model	kVAR	pf	Wind Profile
Edit	Generator.WindGen1	True	0.69	2000	1980	Delta	SimpleInductionMachine	0	1	BuffaloMtn
Edit	Generator.WindGen2	False	12.47	10000	8000	Delta	ConstantPF	0	1	Wind2400

Solve

Voltage Profile | Step [s]: 1 | N steps: 60480 | Amin[pu]: 0.95 | Amax[pu]: 1.05 | Bmin[pu]: .9167 | Bmax[pu]: 1.058

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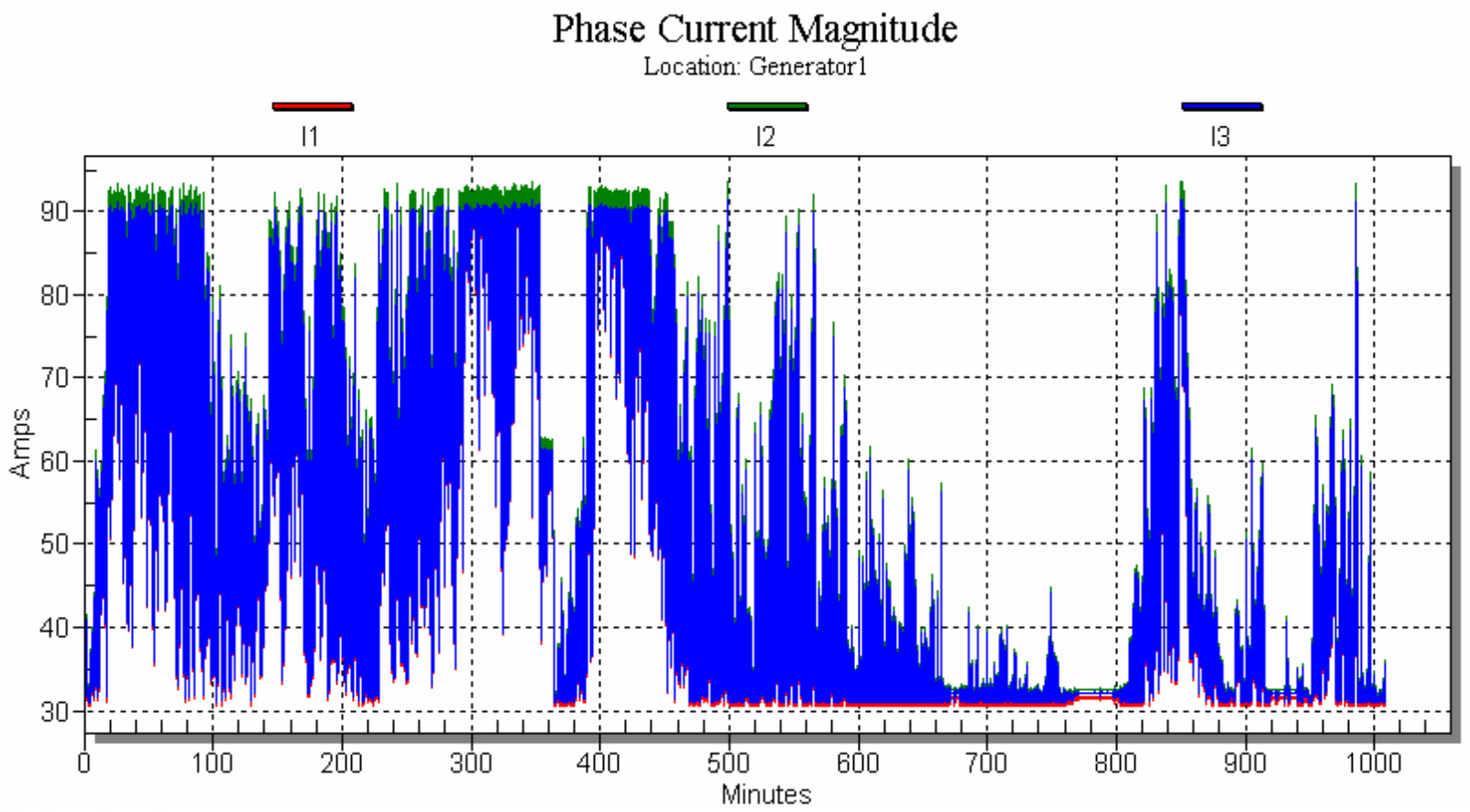
Buffalo Mtn Wind Power Profile



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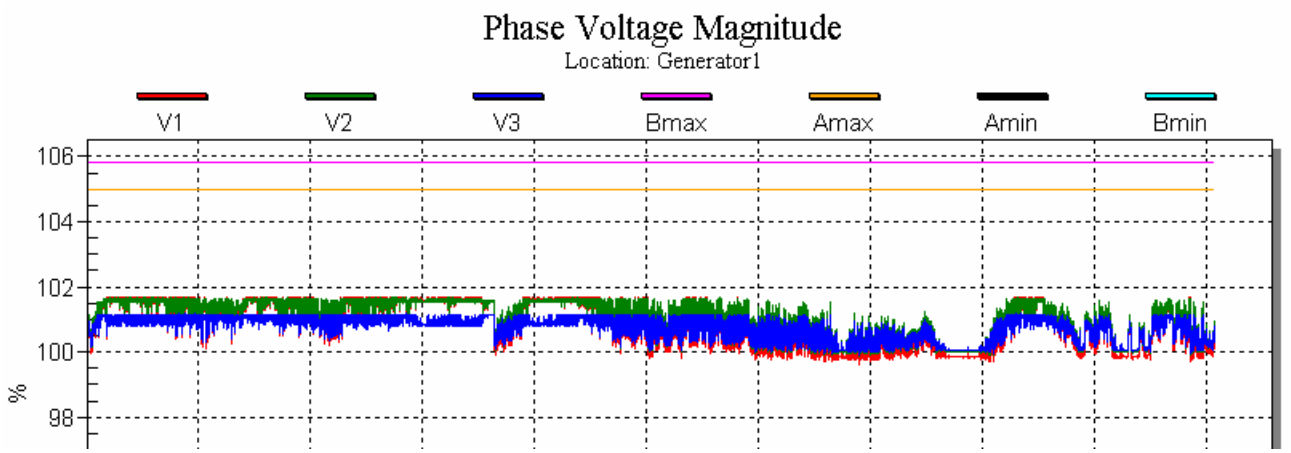
Buffalo Mountain Results



Output

	Location	Continuous P_{ST}	Switching P_{ST}	Switching P_{LT}
◉ Along Feeder	Turbine #1 (end of feeder)	0.67	0.41	0.41
○ Turbine 1	Turbine #2 (mid-feeder)	0.29	0.18	0.18
○ Turbine 2	Mid-feeder	0.29	0.18	0.18
	Source bus	0.00	0.00	0.00

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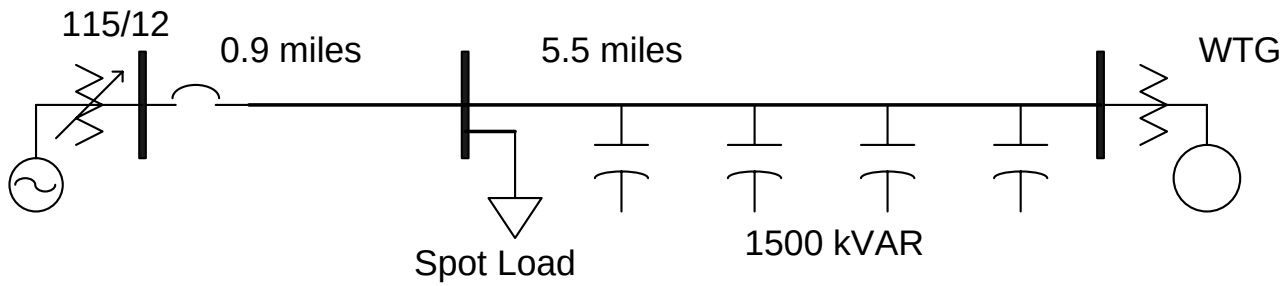
PGE: Hunter's Point

- 12-kV Feeder, 6.4 miles long
- 7-MW minimum load, +/- 6% Phase Unbalance
- Four voltage-controlled capacitor banks total 1500 kVAR
- One large spot load, 2.3 MW
- Data provided in Aspen DistriView



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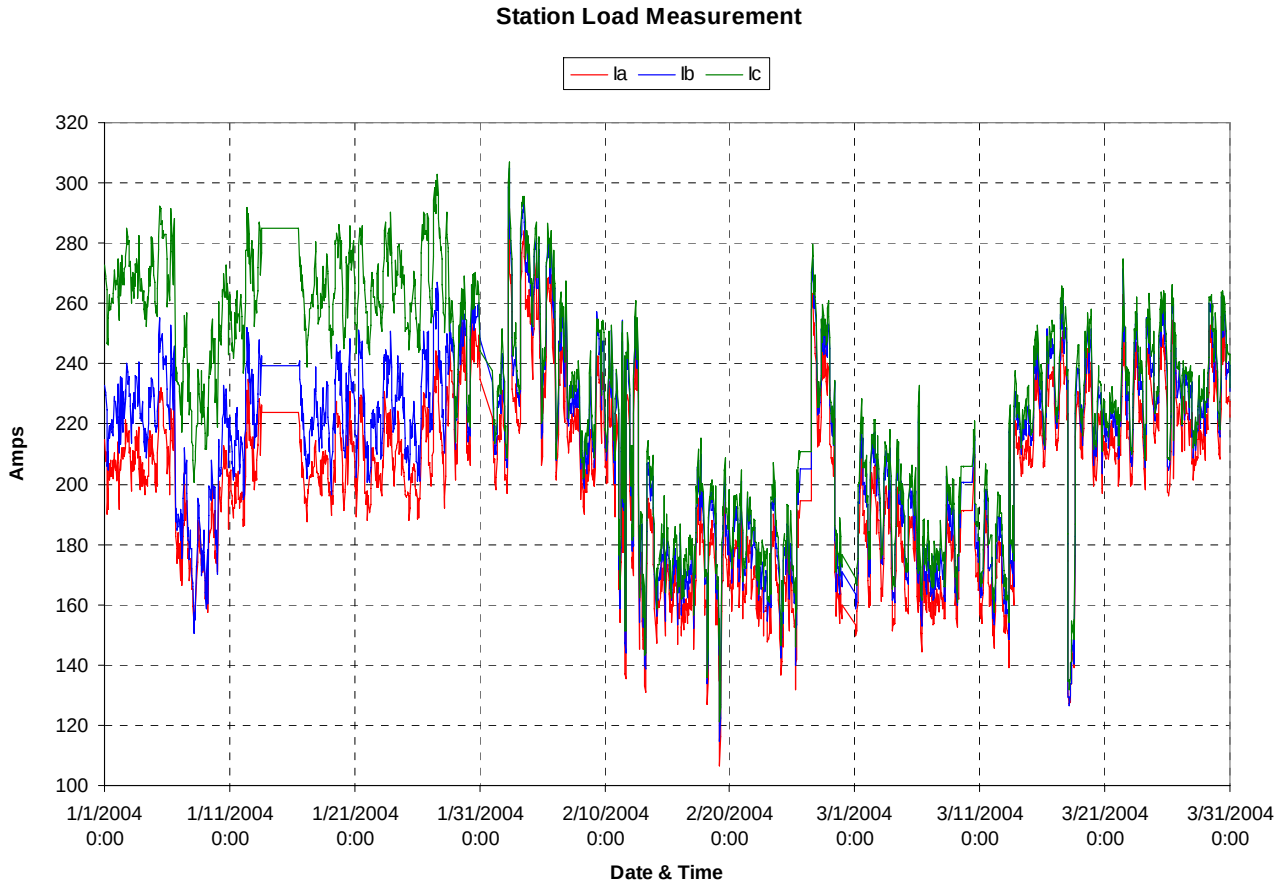
Hunter's Point Load Variations



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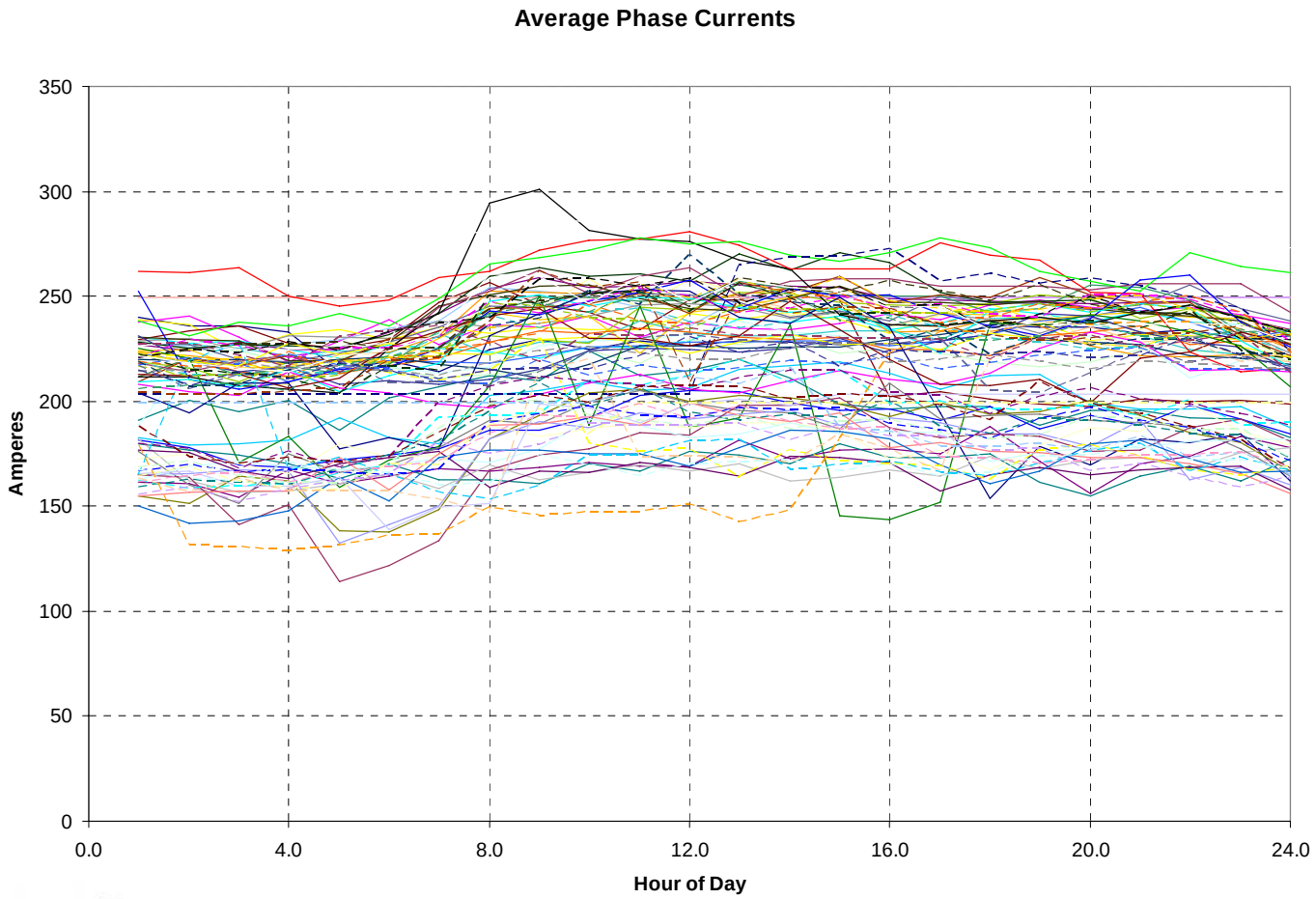
Hunter's Point Hourly Variations



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Hunters Point Wind Speeds

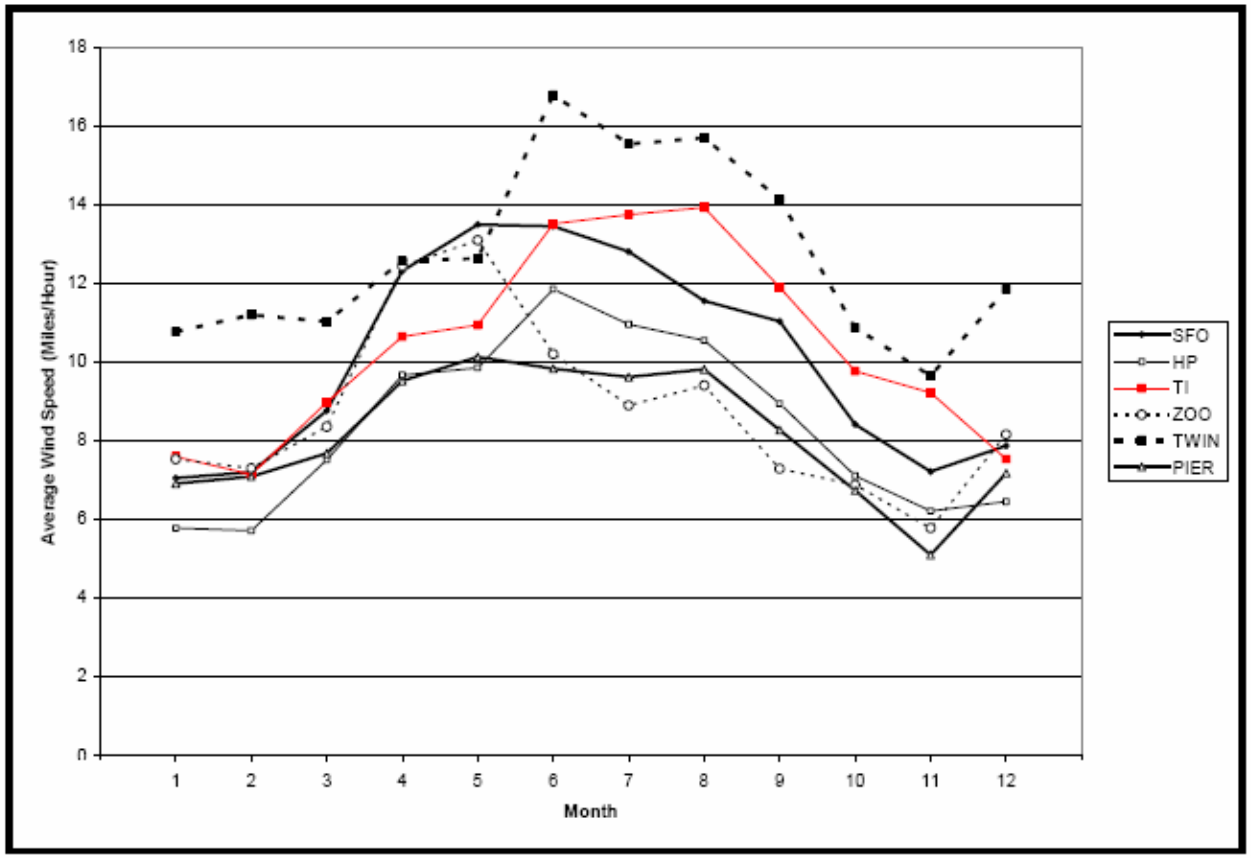

Figure 1 Normalized 33-foot Monthly Average Wind Speeds

IREC: Single Vestas Turbine

- Illinois Rural Electric Cooperative has single 1.65 MW Vestas turbine on feeder 5 miles from the substation
- IREC only did hand-calcs of the voltage drop, so we will help verify by checking the overcurrent coordination, voltage regulation, and flicker with the applets.

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Distributed Wind Users Group

UG Focus and Plans

- Main focus of this user group is to provide input, direction and support for UWIG sponsored activities in this area
- Major short term plan is on the continuation and completion of the Distributed Wind Project
- Longer term plans include the continuing refinement of the tools and deliverables to support the evolving landscape, i.e. FERC small generator interconnection NOPR, IEEE 1547, IEC TC 88

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