Wind Power Intermittency

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Overview

- Extension of work with Davis Power Consultants and the California Energy Commission
- Prior Analysis
  - Examine magnitude and frequency of contingency overloads as a simple measure of system reliability
  - Compare base cases to those with different penetrations of distributed renewable resources

Overview

- Intermittency Analysis
  - Integrate the contingency overloads over time to study the impact of wind intermittency on system reliability
  - Use Simulator's Time Step Simulation (TSS) to model time-varying wind production
  - TSS enables collection and analysis of a large amount of data with a modest investment in setup time

Intermittency Challenges

- Wind plants are generally developed… where the wind blows!
- If EHV transmission is in the vicinity, it is usually by coincidence
- Wind production is unpredictable
- Transmission network must support a multitude of wind production patterns across varying:
  - load conditions
  - production patterns of thermal and hydro resources

Wind Turbine String

Typical Wind “Transmission”

Intermittency Challenges

- Wind production is usually highest during off-peak hours
  - Fast load following resources are off-line
  - Moderated in California, where even simple cycle units may serve as base load resources
- Voltage regulation
  - Var-producing generators are often distant
  - LTCs and caps must switch frequently

Summary of Prior Analysis

- Identify links between electricity needs in the future and available renewable resources.
- Optimize development and deployment of renewable resources based on their benefits to:
  - Electricity system
  - Environment
  - Local economies
- Develop a research tool that integrates spatial resource characteristics and planning analysis.

Objectives

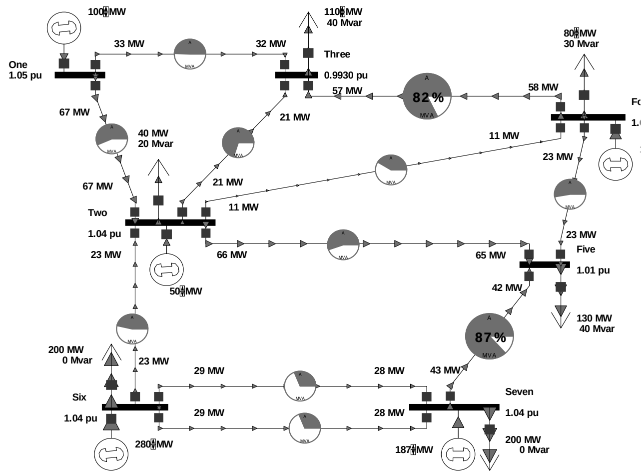
- Investigate the extent to which renewable distributed electricity generation can help address transmission constraints
- Determine performance characteristics for generation, transmission and renewable technology
- Identify locations within system where sufficient renewable generation can effectively address transmission problems

Objectives

- Determine the impact of large-scale distributed projects on grid security.
- We need to:
  - Identify weak transmission elements and define metrics that assess system security.
  - Find locations where new generation would enhance the security of the grid.
  - Combine maps of beneficial locations with maps of energy resources.

Normal Operation Example

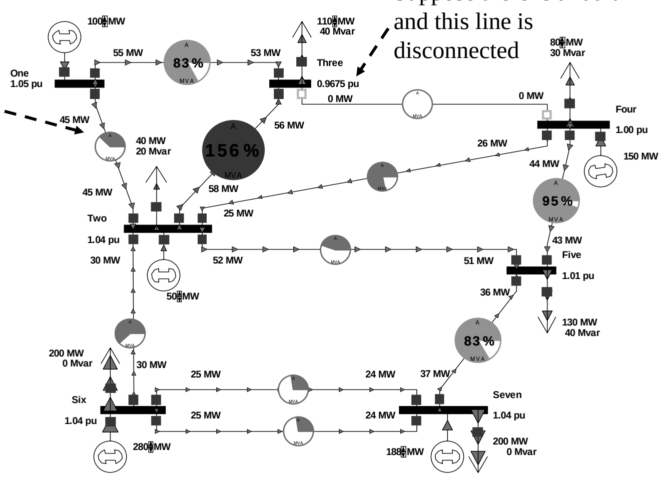
System does not have normal operation thermal violations



Contingency Example

Then this line gets overloaded
(is a **weak element**)
This is a serious problem for the system

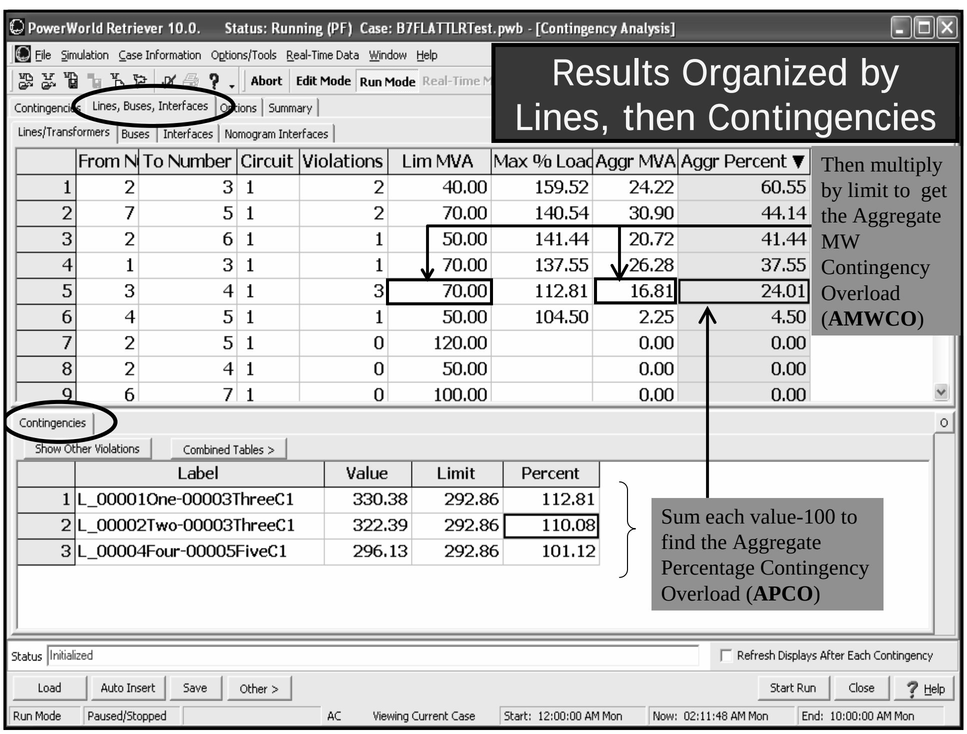
Suppose there is a fault and this line is disconnected



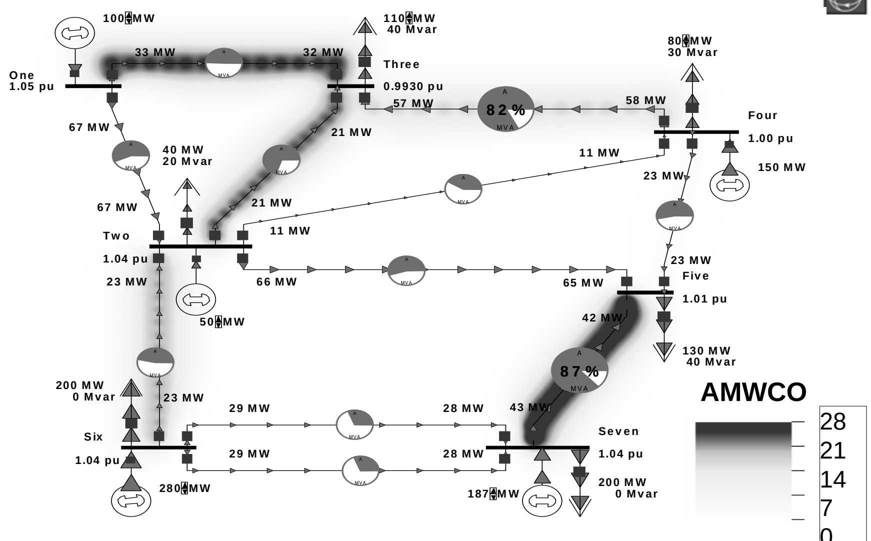
Planning Solutions:
New line to bus 3
OR
New generation
at bus 3

Contingency Analysis

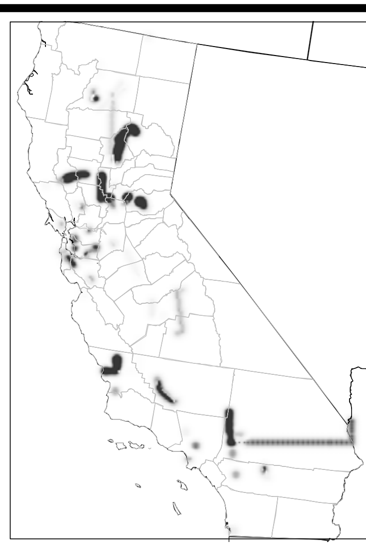
- Security is determined by the ability of the system to withstand equipment failure.
- Define weak elements as those that become overloaded during contingency conditions (congestion).
- Perform N-1 contingency analysis simulation.
- Apply ranking to help prioritize transmission planning: Aggregate MW Contingency Overload (AMWCO)



Weak Element Visualization



Weak Element Visualization



Intermittency Analysis:
Time-Step Simulation

- 2100 MW wind capacity across five regions
- Historic hourly wind production capacity factors are known for each region
- Apply known capacity factors to existing and planned capacity to create simulation inputs
- Match production patterns to characteristic power flow cases
  - Apply summer peak pattern to summer peak case, winter peak pattern to winter peak case, etc.
  - Hold load constant within each case
- Follow the wind production with natural gas resources

Intermittency Analysis:
Time-Step Simulation

- Run contingency analysis at each step
- Store results for each line and transformer at each hourly time step
  - AMWCO for contingencies
  - % of limit used for each base case (non-contingent operation)
- Extend AMWCO metric over time: Aggregate MWh Contingency Overload
- Examine variability of results
- Identify potentially vulnerable transmission paths

Wind Generation in California

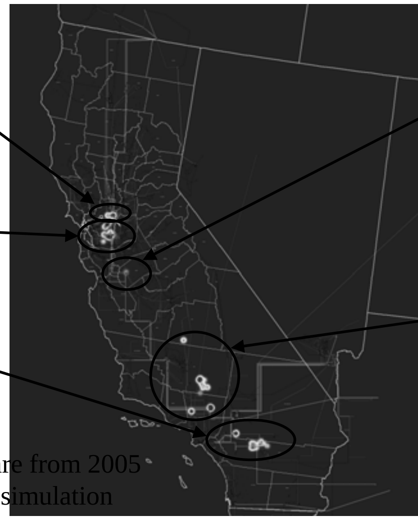
Solano County: 230 MW

Altamont Pass: 600 MW

San Gorgonio Pass: 500 MW

Pacheco Pass: 13 MW

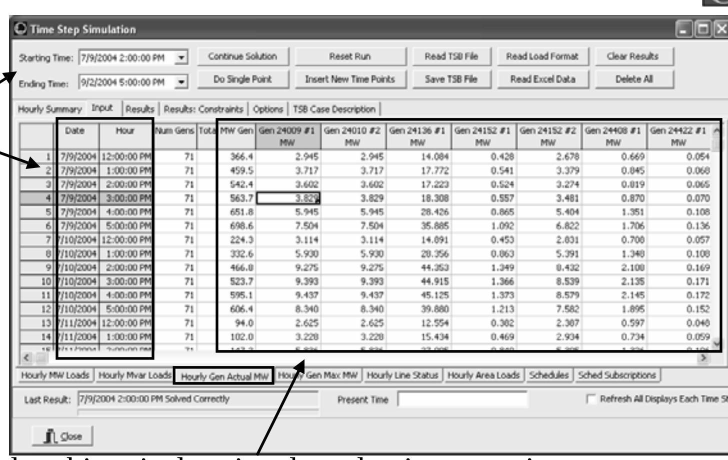
Tehachapi: 800 MW (additional 4000 MW planned)



Note: capacities shown are from 2005 power flow case used in simulation

Input Data:
Hourly Gen MW for each Wind Generator

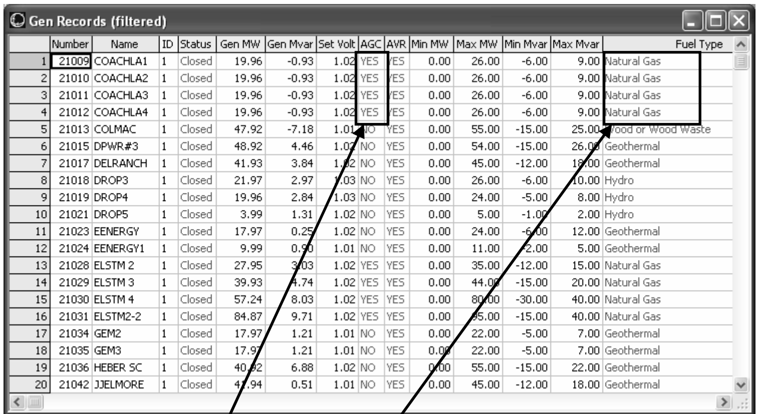
336 time points representing summer peak hours



	Date	Hour	Num Gens	Tota	MW Gen	Gen 24009 #1 MW	Gen 24010 #2 MW	Gen 24136 #1 MW	Gen 24152 #1 MW	Gen 24152 #2 MW	Gen 24408 #1 MW	Gen 24422 #1 MW
1	7/9/2004	12:00:00 PM	71		366.4	2.945	2.945	14.084	0.428	2.678	0.669	0.054
2	7/9/2004	1:00:00 PM	71		459.5	3.717	3.717	17.772	0.541	3.379	0.845	0.068
3	7/9/2004	2:00:00 PM	71		542.4	3.602	3.602	17.223	0.524	3.274	0.819	0.065
4	7/9/2004	3:00:00 PM	71		563.7	3.829	3.829	18.308	0.557	3.481	0.870	0.070
5	7/9/2004	4:00:00 PM	71		651.8	5.945	5.945	28.426	0.865	5.404	1.351	0.108
6	7/9/2004	5:00:00 PM	71		698.6	7.504	7.504	35.885	1.092	6.822	1.706	0.136
7	7/10/2004	12:00:00 PM	71		224.3	3.114	3.114	14.891	0.453	2.831	0.708	0.057
8	7/10/2004	1:00:00 PM	71		332.6	5.930	5.930	28.356	0.863	5.391	1.348	0.108
9	7/10/2004	2:00:00 PM	71		466.8	9.275	9.275	44.353	1.349	8.432	2.108	0.169
10	7/10/2004	3:00:00 PM	71		523.7	9.393	9.393	44.915	1.366	8.539	2.135	0.171
11	7/10/2004	4:00:00 PM	71		595.1	9.437	9.437	45.125	1.373	8.579	2.145	0.172
12	7/10/2004	5:00:00 PM	71		606.4	8.340	8.340	39.880	1.213	7.582	1.895	0.152
13	7/11/2004	12:00:00 PM	71		94.0	2.625	2.625	12.554	0.382	2.387	0.597	0.048
14	7/11/2004	1:00:00 PM	71		102.0	3.228	3.228	15.434	0.469	2.934	0.734	0.059

Values based on historical regional production capacity factor, applied to simulated regional capacity

Input Data:
Follow Wind with Natural Gas



Gen Records (filtered)

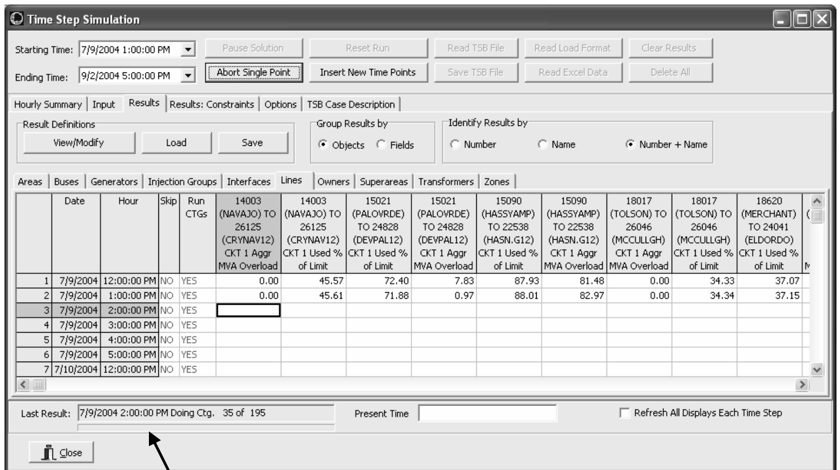
	Number	Name	ID	Status	Gen MW	Gen Mvar	Set Volt	AGC	AVR	Min MW	Max MW	Min Mvar	Max Mvar	Fuel Type
1	21009	COACHLA1	1	Closed	19.96	-0.93	1.02	YES	YES	0.00	26.00	-6.00	9.00	Natural Gas
2	21010	COACHLA2	1	Closed	19.96	-0.93	1.02	YES	YES	0.00	26.00	-6.00	9.00	Natural Gas
3	21011	COACHLA3	1	Closed	19.96	-0.93	1.02	YES	YES	0.00	26.00	-6.00	9.00	Natural Gas
4	21012	COACHLA4	1	Closed	19.96	-0.93	1.02	YES	YES	0.00	26.00	-6.00	9.00	Natural Gas
5	21013	COLMAC	1	Closed	47.92	-7.18	1.01	NO	YES	0.00	55.00	-15.00	25.00	Wood or Wood Waste
6	21015	DPWR#3	1	Closed	48.92	4.46	1.02	NO	YES	0.00	54.00	-15.00	26.00	Geothermal
7	21017	DELRANCH	1	Closed	41.93	3.84	1.02	NO	YES	0.00	45.00	-12.00	18.00	Geothermal
8	21018	DROP3	1	Closed	21.97	2.97	1.03	NO	YES	0.00	26.00	-6.00	10.00	Hydro
9	21019	DROP4	1	Closed	19.96	2.84	1.03	NO	YES	0.00	24.00	-5.00	8.00	Hydro
10	21021	DROP5	1	Closed	3.99	1.31	1.02	NO	YES	0.00	5.00	-1.00	2.00	Hydro
11	21023	EENERGY	1	Closed	17.97	0.25	1.02	NO	YES	0.00	24.00	-6.00	12.00	Geothermal
12	21024	EENERGY1	1	Closed	9.99	0.90	1.01	NO	YES	0.00	11.00	-2.00	5.00	Geothermal
13	21028	ELSTM 2	1	Closed	27.95	3.03	1.02	YES	YES	0.00	35.00	-12.00	15.00	Natural Gas
14	21029	ELSTM 3	1	Closed	39.93	4.74	1.02	YES	YES	0.00	44.00	-15.00	20.00	Natural Gas
15	21030	ELSTM 4	1	Closed	57.24	8.03	1.02	YES	YES	0.00	80.00	-30.00	40.00	Natural Gas
16	21031	ELSTM2-2	1	Closed	84.87	9.71	1.02	YES	YES	0.00	95.00	-15.00	40.00	Natural Gas
17	21034	GEM2	1	Closed	17.97	1.21	1.01	NO	YES	0.00	22.00	-5.00	7.00	Geothermal
18	21035	GEM3	1	Closed	17.97	1.21	1.01	NO	YES	0.00	22.00	-5.00	7.00	Geothermal
19	21036	HEBER SC	1	Closed	40.92	6.88	1.02	NO	YES	0.00	55.00	-15.00	22.00	Geothermal
20	21042	JJELMORE	1	Closed	41.94	0.51	1.01	NO	YES	0.00	45.00	-12.00	18.00	Geothermal

AGC set to YES for Natural Gas units, NO for others

Contingency Analysis

- Set Each Hourly Field (Run CTGs) to YES
- Time Saving Measures
  - Filter the N-1 contingency list
    - Include only contingencies that cause overloads in the base case (before applying any hourly scenario)
    - Reduced number from 5000+ to 195
  - Use linearized lossless DC calculation

Results Grid

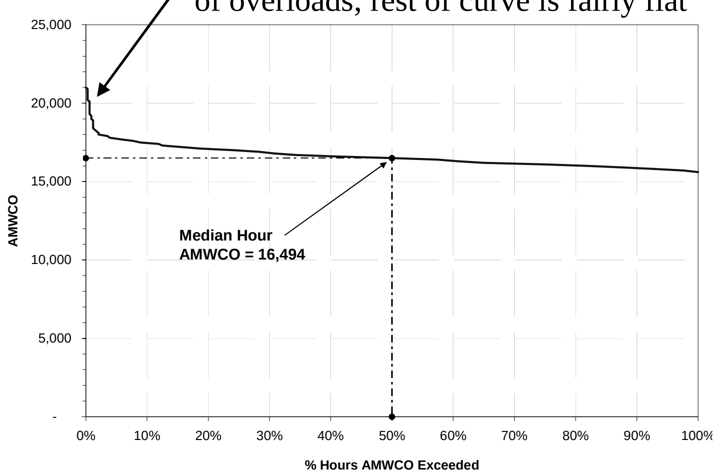


	Date	Hour	Skip	Run CTGs	14003 (NAVAJO) TO 26125 (CRYNAV12) CKT 1 Aggr MVA Overload	14003 (NAVAJO) TO 26125 (CRYNAV12) CKT 1 Used % of Limit	15021 (PALOVRDE) TO 24828 (DEVPAL12) CKT 1 Used % of Limit	15021 (PALOVRDE) TO 24828 (DEVPAL12) CKT 1 Aggr MVA Overload	15090 (HASSYAMP) TO 22538 (HASN.G12) CKT 1 Used % of Limit	15090 (HASSYAMP) TO 22538 (HASN.G12) CKT 1 Aggr MVA Overload	18017 (TOLSON) TO 26046 (MCCULLGH) CKT 1 Aggr MVA Overload	18017 (TOLSON) TO 26046 (MCCULLGH) CKT 1 Used % of Limit	18620 (MERCHANT) TO 24041 (ELDORDO) CKT 1 Used % of Limit
1	7/9/2004	12:00:00 PM	NO	YES	0.00	45.57	72.40	7.83	87.93	81.48	0.00	34.33	37.07
2	7/9/2004	1:00:00 PM	NO	YES	0.00	45.61	71.88	0.97	88.01	82.97	0.00	34.34	37.15
3	7/9/2004	2:00:00 PM	NO	YES									
4	7/9/2004	3:00:00 PM	NO	YES									
5	7/9/2004	4:00:00 PM	NO	YES									
6	7/9/2004	5:00:00 PM	NO	YES									
7	7/10/2004	12:00:00 PM	NO	YES									

Contingency analysis shown in process

System AMWCO Duration

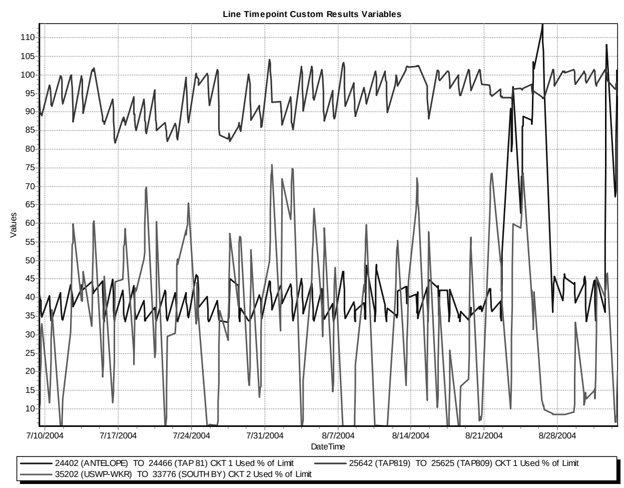
A few hours experience unusually high level of overloads; rest of curve is fairly flat



Hourly Line Loadings

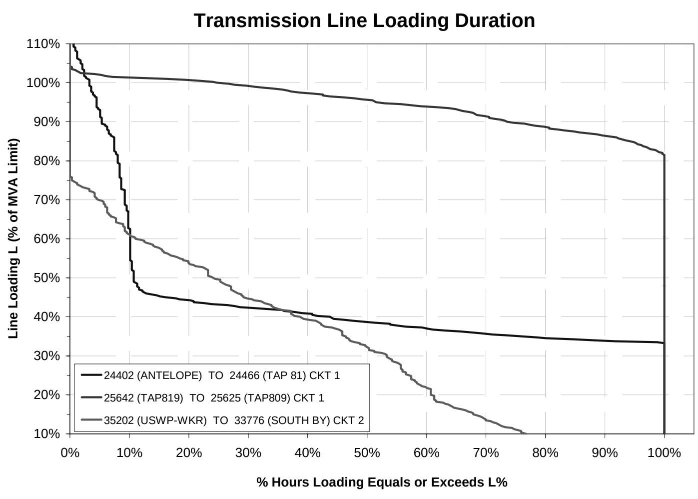
These three lines show very different loading patterns:

- Red: high average loading, low variability
- Green: low avg loading, high variability
- Blue: low avg loading, low variability overall, but heavily impacted during certain conditions



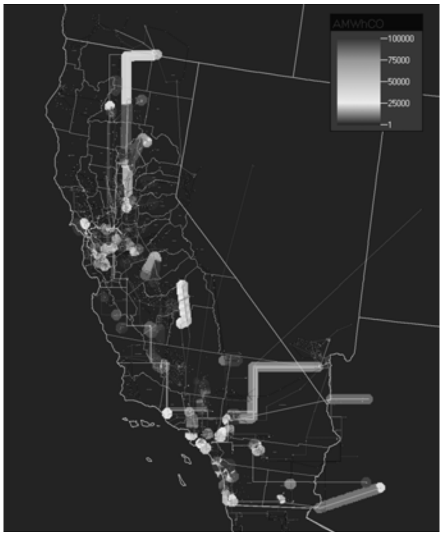
Line Loading Duration Curve

Shown are the same three lines from prior slide



Aggregate MWh Contingency Overload (AMWhCO)

Red indicates lines most severely overloaded over time



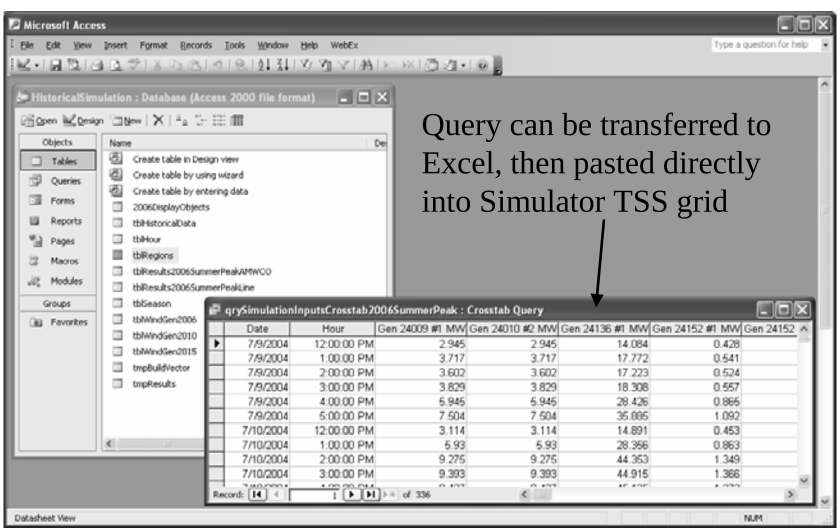
Overload Variability

- Shows AMWhCO relative to a reference (median hour)
- Many overloaded lines experience consistent levels at nearly every hour – wind intermittency is not a big factor
- Red indicates lines most adversely affected by intermittency
- Green indicates lines favorably affected by intermittency

Time-Step Simulation

- TIP: It is helpful to use an external database for managing TSS inputs and results
  - Perform calculations to determine inputs
  - Paste inputs into TSS grid
  - Query and filter based on statistical criteria
  - Create time-integrated graphs
  - Paste time-integrated results into Simulator's custom float fields for contouring

Database:
Manage Inputs and Results



Conclusions

- As integration of wind power on the grid increases, intermittency issues will become more significant
- Simulator's TSS offers a robust and efficient environment for studying time-scale phenomenon such as wind intermittency
  - Easy to set up, especially for a modest number of input variables
  - Many results can be stored and accessed within the Simulator TSB file without having to catalog multiple power flow cases

Conclusions

- An external database may be very helpful for preparing inputs, screening results, and integrating results over time
- Some plots are available in Simulator for viewing inputs and results
- Complex plots may be readily produced from a good external database