PJM Markets 201

Generation Contingency Analysis

PJM State & Member Training Dept.

Objectives

Student will be able to:

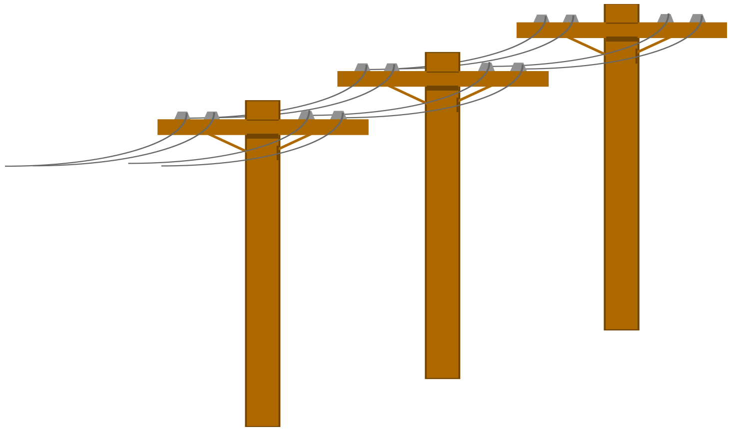
- Describe the processes and tools associated with performing contingency analysis
  - Identify the procedure for re-dispatching generation to alleviate an overloaded monitored transmission line caused by a contingency

Operational Limits

- **Thermal Limits -** Thermal limits are due to the heat dissipation capability of power system equipment

- **Voltage Limits -** Utility and customer equipment is designed to operate at a certain supply voltage (or a small range around an ideal voltage)

- **Stability Limits -** Refers to the power system maintaining a state of equilibrium



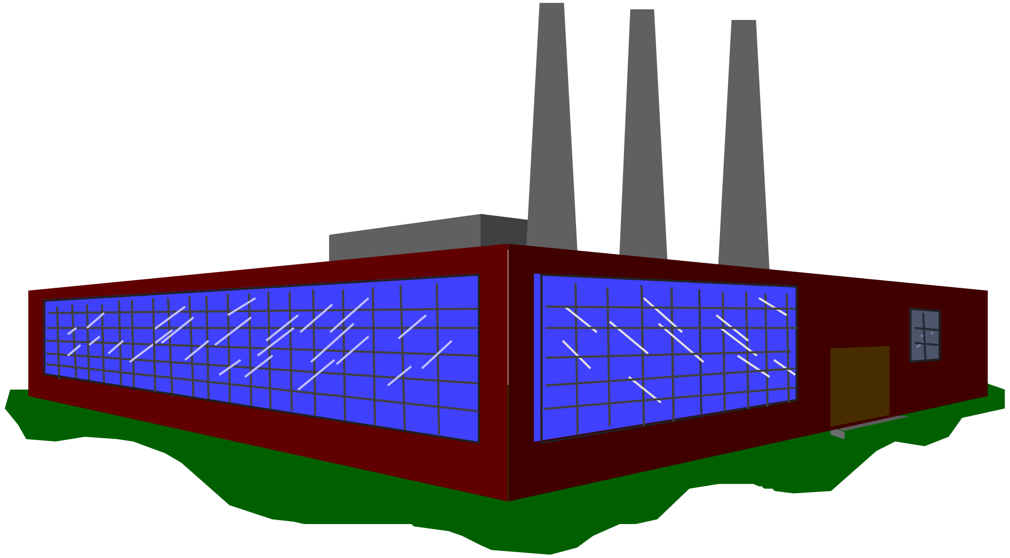
Control Actions

- There are three basic types of actions that can be performed to control the flow of power on the electric system:

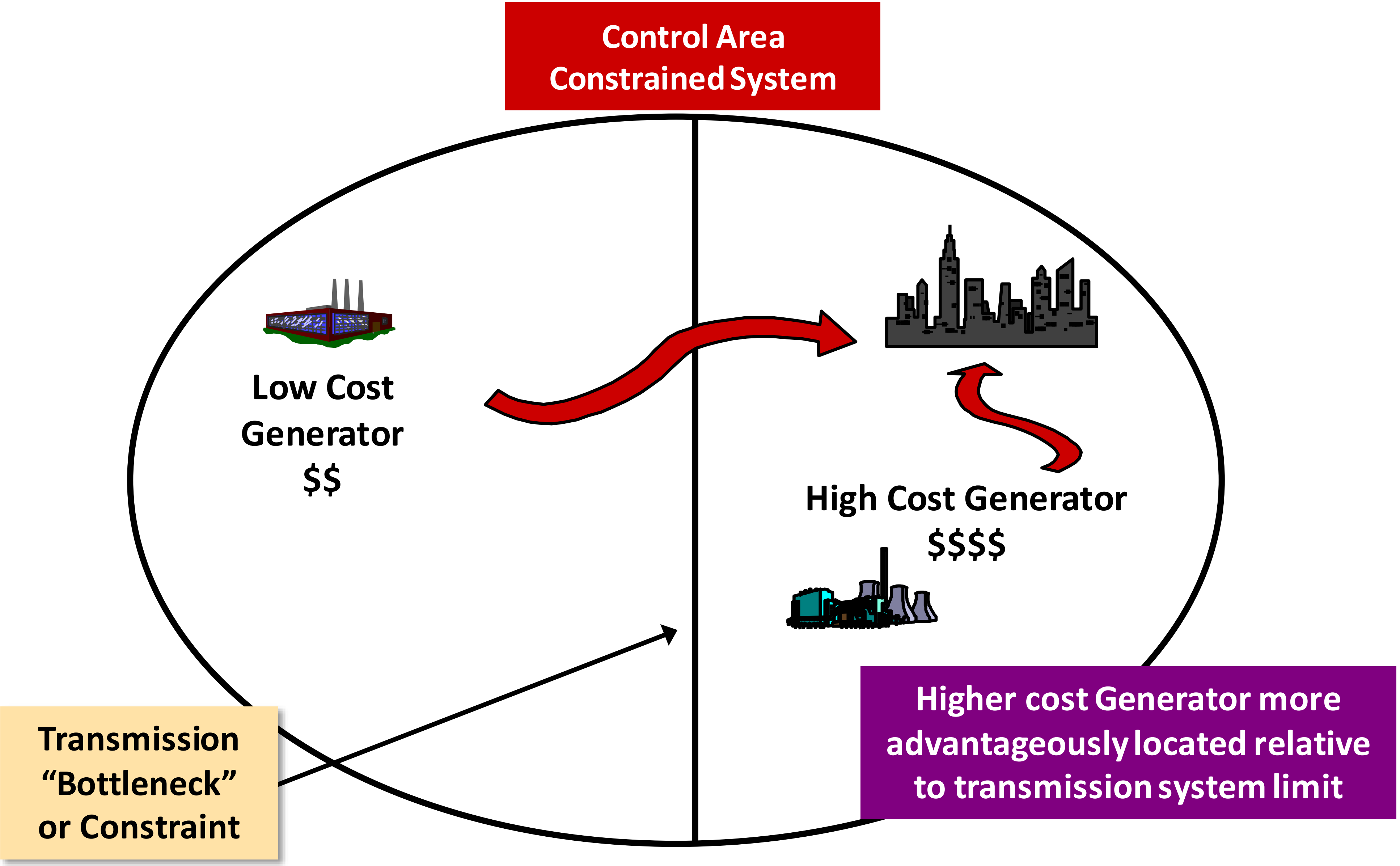
❶ System Reconfiguration

❷ Transaction Curtailments

❸ Redispatch Generation

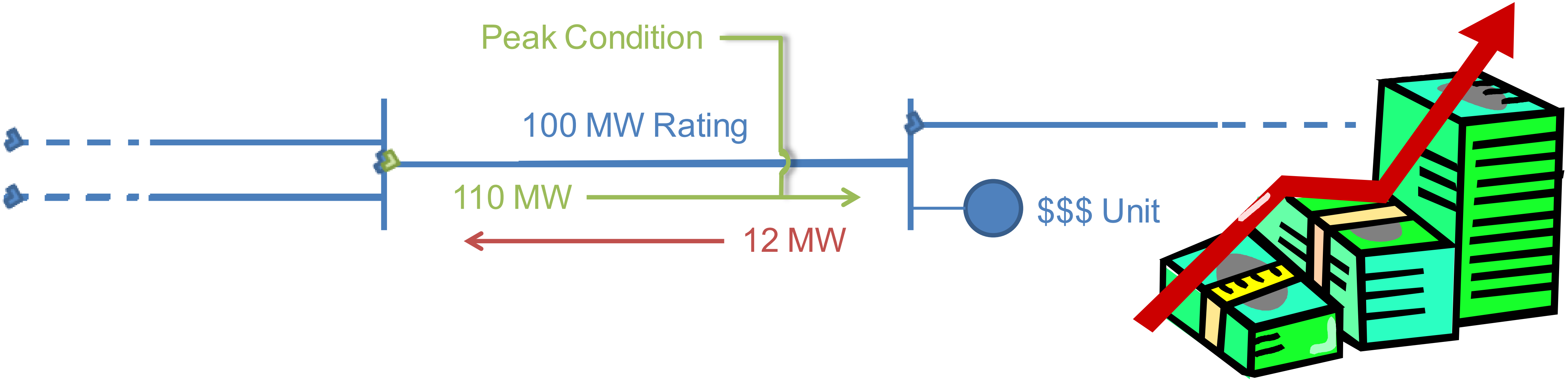


Security Constrained Re-Dispatch



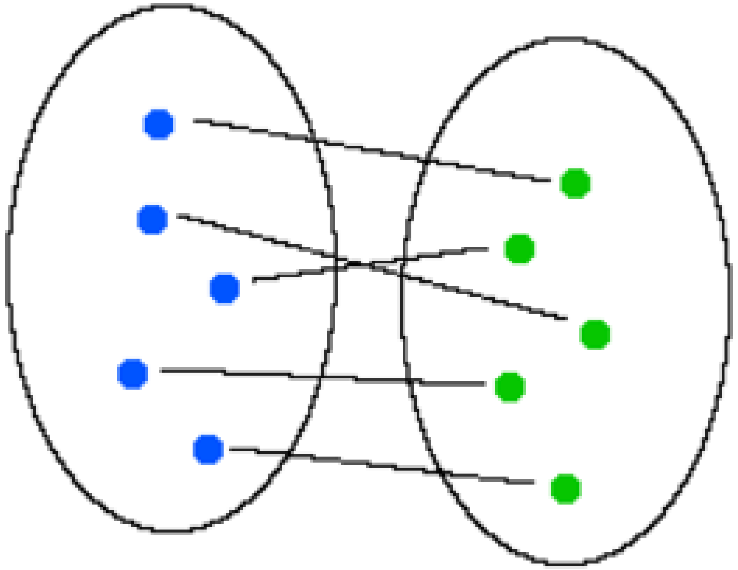
When Constraints Occur...

- Delivery limitations prevent use of "next least-cost generator"
- Higher-cost generator closer to load must be used to meet demand
- Cost expressed as "security constrained redispatch cost"



Constraints & Marginal Units

- There will always be at least one marginal unit
  - System Energy Unit
- There will be an additional marginal unit for each binding constraint
- It is possible, and in fact likely, that there will be multiple marginal units for a given time interval



Contingency Analysis

- “What if" scenario simulator that evaluates, provides and prioritizes the impacts on an electric power system when problems occur.
  - A contingency is a provision for an unforeseen event or circumstance
    - Loss or failure of a small part of the power system (e.g. a transmission line)
    - Loss or failure of individual equipment such as a generator or transformer
- A computer application that uses a simulated model of the power system
  - Evaluates the effects of an outage event
  - Calculates any overloads that may result
- This is referred to as maintaining system security

Contingency Analysis

- Contingency Analysis is essentially a "preview" analysis tool
  - It simulates and quantifies the results of problems that could occur in the power system in the immediate future
- Contingency Analysis is used as a study tool for the off-line analysis of contingency events, and as an on-line tool to show operators what would be the effects of future outages
  - This allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

How Contingency Analysis Works

- Executes a power flow analysis for each potential problem that is defined on a contingency list
  - A contingency list contains each of the elements that will be removed from the network model, one by one, to test the effects for possible overloads of the remaining elements
  - The failure or outage of each element in the contingency list is simulated in the network model by removing that element
  - The resulting network model is solved to calculate the resulting power flows, voltages, and currents for the remaining elements of the model

Generation Re-dispatch

For Contingency Analysis

PJM Real Time Contingency Operations

- Review available controlling actions and the distribution factor (DFax) effect on the overloaded facility.
  - Consider whether there are sufficient resources available to control transmission facilities within acceptable limits.
- Initiate off-cost if reasonable controlling actions are available
- SCED works best when the impacts are 5% or greater but can still be utilized when only lower DFax values exist

PJM Real Time Contingency Operations

- Once off-cost is initiated, RT-SCED will redispatch generation based on its dollar per MW effect, considering all on-line flexible units with an impact of ~1% or greater
  - This percentage may be adjusted on a case by case basis
- Initiate a Post Contingency Local Load Relief Warning/Action if post-contingency flows exceed designated ratings and insufficient resources are available to control the overloaded facilities

Real Time Contingency Operations

- During Constrained Operations, resources will redispatched cost-effectively based on their bid parameters

- **Cost-effective redispatch ($/MW Effect) = (Current Dispatch Rate – Unit Bid)/Unit Shift Factor**
  - SMP and Marginal Cost of Unit values are the result of optimization

- Units with lowest $/MW effect are used to re-dispatched when the system is constrained

DFAX sign	$/MW Effect for Raising Output	$/MW Effect for Lowering Output
Negative DFAX = Raise Help	**Choose Lowest**	Choose Highest
Positive DFAX = Lower Help	Choose Highest	**Choose Lowest**

- Unit parameters are taken into account and honored (i.e. eco min, eco max, min run time, etc.)

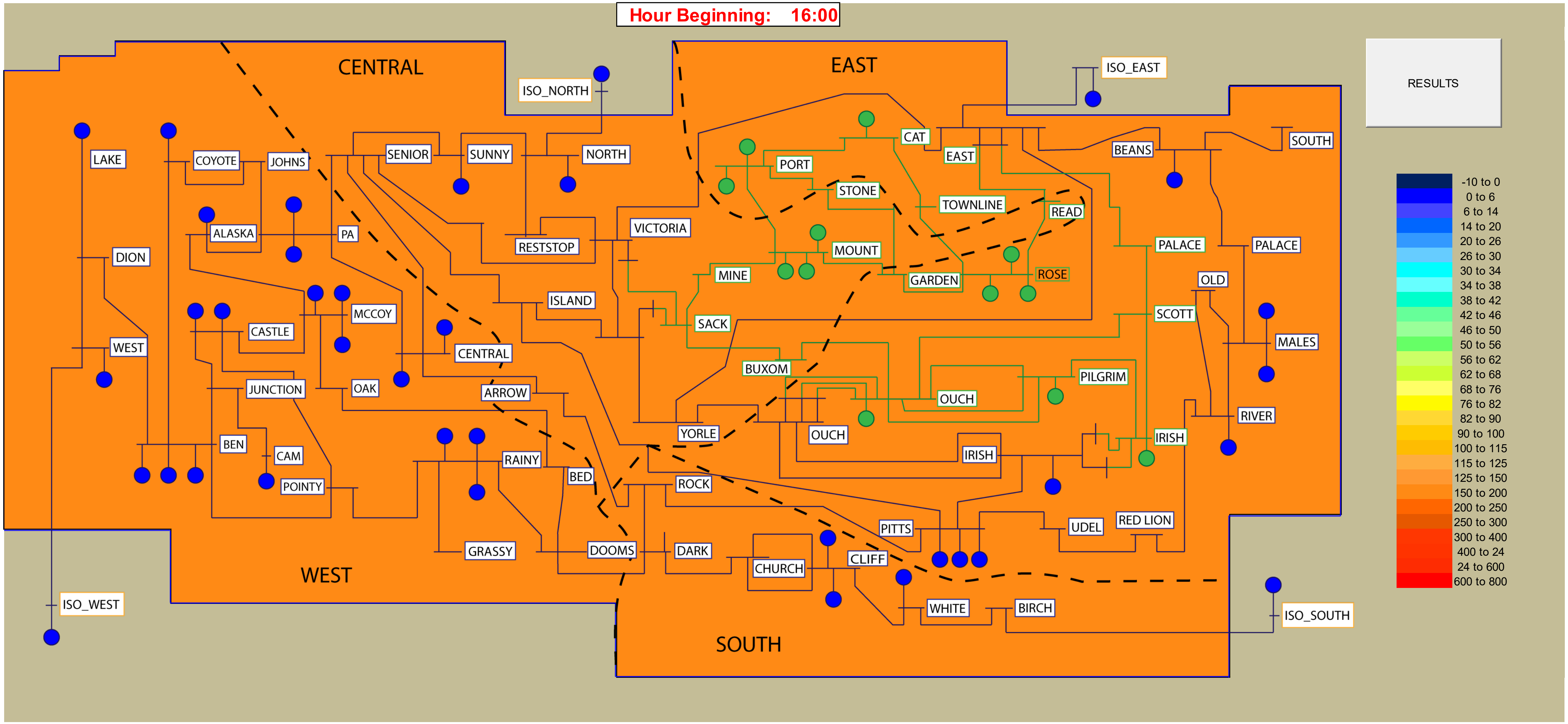
Generation Shift Factors

Generation Shift Factors

- The change (or sensitivity) of active power flow in a reference direction on a transmission line with respect to a change in injection at the generator bus and a corresponding change in withdrawal at the reference bus
  - Calculated with a DC Power Flow
- Shift Factors change when:
  - Transmission topology changes
  - Line impedance changes
- Also known as Generation DFax

Contingency Analysis Demo

Base Case – LMP Contour Map



Base Case – Marginal Unit – No Constraints

Marginal Unit Report							
HH:MM	**BidName**	**Zone**	**BTyp**	**LMP**	**Offer**	**DisptMW**	**OrgName**
16:00	PILGRIM CC1 F	EAST	Gens	170	170	451.8	Harris Power

Calculate DFAX Using DC Power Flow

Contingency List: Oak - McCoy 500 KV Line	
Monitored Line: Rainy - Dooms 500 KV Line	
Using DC Power Flow	
Rainy - Dooms 500 KV Line Limit (MW) =	1990
Contingency MW Flow =	2,468.0010
MW Over Limit =	478.0010
Current Dispatch Rate ($/MWh) =	169.99

Calculate DFAX Using DC Power Flow

pnodeid	unitid	unitname	DFAX Flow	DFAX	Base Case MW Dispatch
33645435	20210120	OUCH CC	2467.9915	-0.0095	0.000
50402	10102230	BEANS CT	2467.9916	-0.0094	0.000
48217747	10600101	ROSE CC	2467.9965	-0.0045	525.000
50463	10202491	ROSE CT1	2467.9965	-0.0045	40.100
34887829	96360102	ROSE ST	2467.9965	-0.0045	93.500
17461203	51300101	PILGRIM CC1	2467.9913	-0.0097	451.800
34887997	96160101	RAINY 1	2468.4354	0.4344	526.000
34887999	96160102	RAINY 2	2468.4354	0.4344	530.000
34888001	96160103	RAINY 3	2468.4354	0.4344	504.000
5021723	90050101	CASTLE 1	2468.2881	0.2871	500.000
5021724	90050102	CASTLE 2	2468.2881	0.2871	500.000
51019	90060101	BEN 1	2468.3016	0.3006	640.000
51020	90060102	BEN 2	2468.3016	0.3006	640.000
51021	90060103	BEN 3	2468.3016	0.3006	620.000
5021731	90070101	MCCOY 1	2468.2642	0.2632	520.000
5021732	90070102	MCCOY 2	2468.2642	0.2632	450.000
5021733	90070103	MCCOY 3	2468.2642	0.2632	460.000
29782805	90070104	COYOTE 1	2468.2274	0.2264	520.000
34509201	90070105	CAM 1	2468.2903	0.2893	520.000
5021743	90100101	WEST 1	2468.3016	0.3006	650.000
5021744	90100102	LAKE 1	2468.3016	0.3006	525.000
50781	53610110	PA 1	2468.1523	0.1513	850.000

pnodeid	unitid	unitname	DFAX Flow	DFAX	Base Case MW Dispatch
50782	53610120	PA 2	2468.1523	0.1513	850.000
50769	53620110	CENTRAL 1	2468.1093	0.1083	850.000
50770	53620120	CENTRAL 2	2468.1093	0.1083	850.000
50559	20141101	PITS 1	2467.9631	-0.0379	93.000
50557	20141102	PITS 2	2467.9631	-0.0379	1138.000
50558	20141103	PITS 3	2467.9631	-0.0379	1138.000
50542	20021101	IRISH 1	2467.988	-0.0130	1175.000
50543	20021102	IRISH 2	2467.9897	-0.0113	1165.000
50489	10261210	MALES 1	2467.9733	-0.0277	1200.000
50490	10261220	MALES 2	2467.9733	-0.0277	1070.000
50662	40081201	CLIFF 1	2467.7751	-0.2259	885.000
50661	40081202	CLIFF 2	2467.7751	-0.2259	875.000
50817	60050103	WHITE 3	2467.7751	-0.2259	600.000
50654	31161101	NORTH 1	2468.0206	0.0196	1103.000
32412777	90070106	SUNNY 1	2468.0304	0.0294	450.000
50483	10271110	RIVER 1	2467.9732	-0.0278	1080.000
50748	52440110	PORT 1	2467.9975	-0.0035	150.000
50752	52440120	PORT 2	2467.9975	-0.0035	243.000
50619	31010101	MOUNT 1	2467.9977	-0.0033	93.000
50621	31010103	MOUNT 3	2467.9977	-0.0033	250.000
50622	31010104	MOUNT 4	2467.9977	-0.0033	0.000
50894	80010105	CAT CC	2467.9974	-0.0036	240.000

Constraint Re-dispatch

- Units with lowest $/MW effect are re-dispatched when system is constrained
  - Iterative approach: $/MW recalculated as MW change

Constraint Re-dispatch

- Units with positive Dfax/added flow were decreased
- Units with negative Dfax/removed flow were increased
- This was a peak load case and units with a negative DFax and low $/MW could not be increased since they were at economic max
  - Example – Cliff 1 and 2 at economic max
- Other units with higher $/MW were needed to increase
  - Ouch CC was needed to increase

$/MW Effect Calculation Used in Real-Time Operations

		Base Case			Constrained Case					
unitname	DFAX	MW Dispatch	Bid$@Disp	**$/MW Effect**	MW Dispatch	Bid$@Disp	**$/MW Effect**	Economic Min (MW)	Economic Max (MW)	Delta MW
OUCH CC	-0.0095	0	165	0	355	165	-525.263	355	600	355
PILGRIM CC1	-0.0097	451.8	170	1.030928	496.5	170	1.030928	258	818	44.7
RAINY 2	0.4344	530	34.73	311.372	0	25.51	0	265	530	-530
RAINY 3	0.4344	504	39.84	299.6087	308.5	34.53	311.8324	300	504	-195.5
MCCOY 3	0.2632	460	36.37	507.6748	0	25.9	0	460	520	-460
LAKE 1	0.3006	525	28.82	469.6274	400	27.91	472.6547	250	600	-125
CLIFF 1	-0.2259	885	7.13	-720.938	885	7.13	-720.938	885	885	0
CLIFF 2	-0.2259	875	7.34	-720.009	875	7.34	-720.009	875	875	0
MOUNT 3	-0.0033	250	30.07	-42400	451.4	33.06	-41493.9	250	630	201.4
MOUNT 4	-0.0033	0	52.54	0	430	58.18	-33881.8	250	590	430
CAT CC	-0.0036	240	43.23	-35211.1	420	43.23	-35211.1	200	420	180

Units with positive DFAX are needed to decrease output

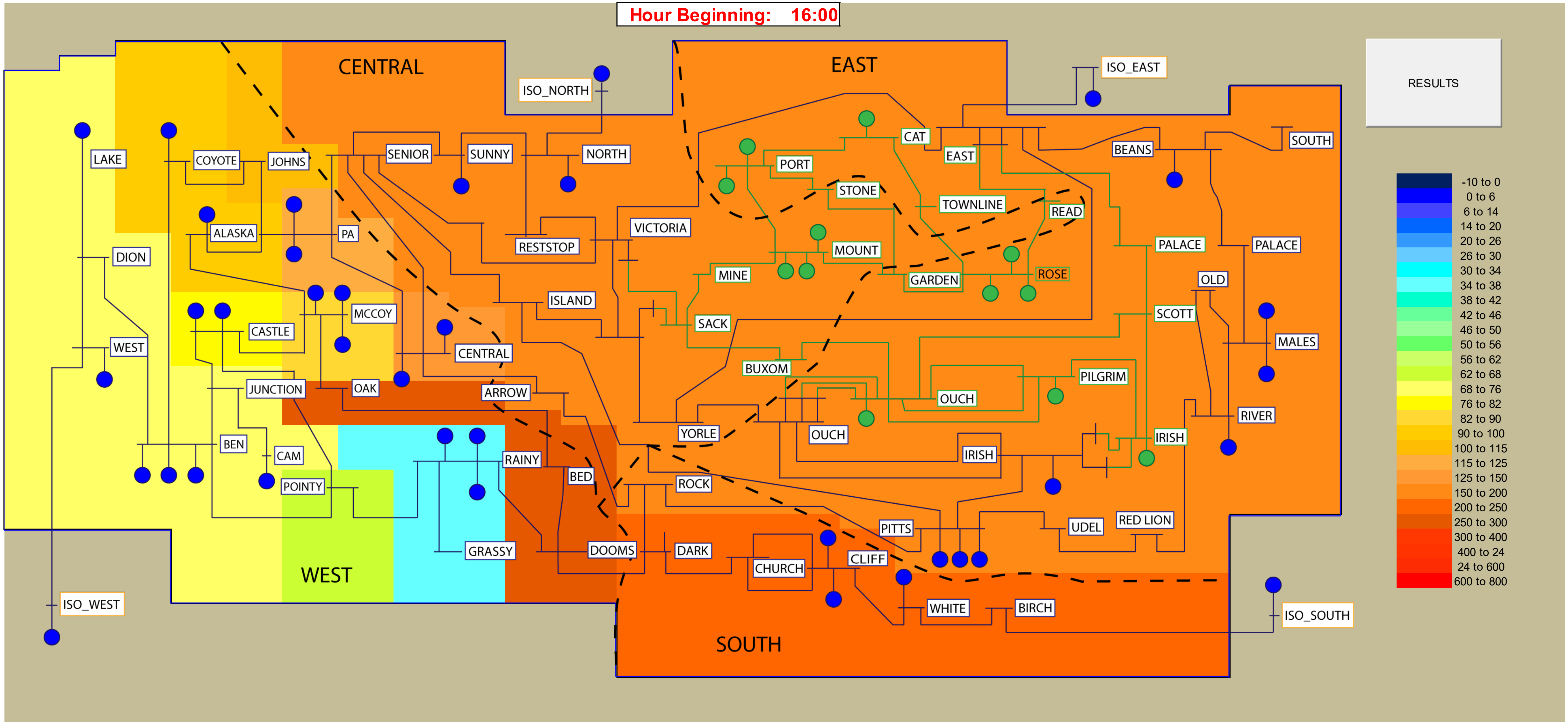
Units with negative DFAX are needed to increase output

$/MW Effect = (Current Dispatch Rate – Unit Bid)/Unit Shift Factor

Current Dispatch Rate = $169.99/MWh

Congestion Price Demo

Constrained Case – LMP Contour Map



Post Contingency Dispatch Summary

- 9 units were re-dispatched to control the constraint
  - Marginal unit setting System Marginal Price was increased
  - 8 other units were adjusted
- The highest cost unit that was decreased is the marginal unit controlling the constraint
  - Rainy 3

Units Re-dispatched to Control Constraint

UnitName	unitType	Zone	Redispatched MW Disptch	Base Case MW Disptch	Delta	Bid$@Disp
MOUNT 3 F	Steam	CENTRAL	451.4	250	201.4	33.06
MOUNT 4 F	Steam	CENTRAL	430	0	430	58.18
PILGRIM CC1 F	Steam	EAST	496.5	451.8	44.7	170
CAT CC	Steam	EAST	420	240	180	43.23
OUCH CC	Steam	EAST	355	0	355	165
RAINY 2	Steam	WEST	0	530	-530	25.51
RAINY 3	Steam	WEST	308.5	504	-195.5	34.53
MCCOY 3 F	Steam	WEST	0	460	-460	25.9
LAKE 1 F	Steam	WEST	400	525	-125	27.91

Shadow Price

- Rainy – Dooms 500 KV line rating is 1990 MVA
- Calculate shadow price for Rainy – Dooms 500 KV line
  - Re-dispatch the system using a DC power flow with Rainy – Dooms rating at 1991 MW
  - Calculate the new total system production cost and subtract that from the post contingency case production cost
    - The difference in production cost is the shadow price

Shadow Price

- Post contingency case production cost = $11,081,725.40
- Production cost with 1 more MW across the Rainy – Dooms 500 KV line = $11,081,422.58
- With 1 more MW across the Rainy – Dooms 500 KV line the saving in Production cost is **-$302.82, which is the shadow price**
  - Pilgrim CC1 decreased by 2.25MW
  - Rainy 3 increased by 2.25 MW

Class Problem – Calculate Change in Rainy – Dooms Line Flow

- Pilgrim CC1 decreased by 2.25MW
  - DFAX (Rainy – Dooms) = -0.0097
- Rainy 3 increased by 2.25 MW
  - DFAX (Rainy – Dooms) = 0.4344

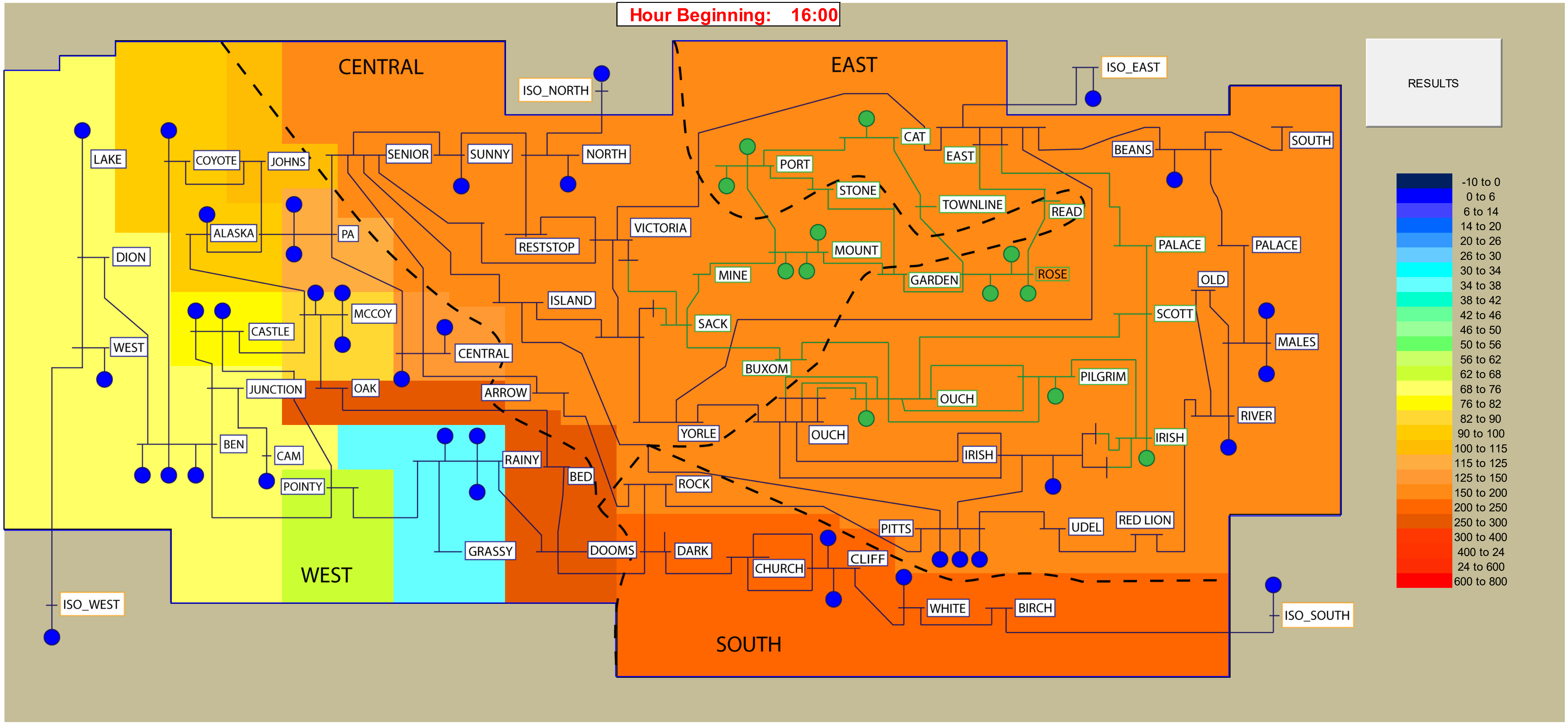
Congestion Component of LMP

Congestion Component = Shadow Price * DFAX

unitname	DFAX	Shadow Price	Congestion Component ($/MWh)
OUCH CC	-0.0095	-302.82	2.88
BEANS CT	-0.0094	-302.82	2.85
ROSE CC	-0.0045	-302.82	1.36
ROSE CT1	-0.0045	-302.82	1.36
ROSE ST	-0.0045	-302.82	1.36
PILGRIM CC1	-0.0097	-302.82	2.94
RAINY 1	0.4344	-302.82	-131.55
RAINY 2	0.4344	-302.82	-131.55
RAINY 3	0.4344	-302.82	-131.55
CASTLE 1	0.2871	-302.82	-86.94
CASTLE 2	0.2871	-302.82	-86.94
BEN 1	0.3006	-302.82	-91.03
BEN 2	0.3006	-302.82	-91.03
BEN 3	0.3006	-302.82	-91.03
MCCOY 1	0.2632	-302.82	-79.70
MCCOY 2	0.2632	-302.82	-79.70
MCCOY 3	0.2632	-302.82	-79.70
COYOTE 1	0.2264	-302.82	-68.56
CAM 1	0.2893	-302.82	-87.61
WEST 1	0.3006	-302.82	-91.03
LAKE 1	0.3006	-302.82	-91.03
PA 1	0.1513	-302.82	-45.82

unitname	DFAX	Shadow Price	Congestion Component ($/MWh)
PA 2	0.1513	-302.82	-45.82
CENTRAL 1	0.1083	-302.82	-32.80
CENTRAL 2	0.1083	-302.82	-32.80
PITS 1	-0.0379	-302.82	11.48
PITS 2	-0.0379	-302.82	11.48
PITS 3	-0.0379	-302.82	11.48
IRISH 1	-0.0130	-302.82	3.94
IRISH 2	-0.0113	-302.82	3.42
MALES 1	-0.0277	-302.82	8.39
MALES 2	-0.0277	-302.82	8.39
CLIFF 1	-0.2259	-302.82	68.41
CLIFF 2	-0.2259	-302.82	68.41
WHITE 3	-0.2259	-302.82	68.41
NORTH 1	0.0196	-302.82	-5.94
SUNNY 1	0.0294	-302.82	-8.90
RIVER 1	-0.0278	-302.82	8.42
PORT 1	-0.0035	-302.82	1.06
PORT 2	-0.0035	-302.82	1.06
MOUNT 1	-0.0033	-302.82	1.00
MOUNT 3	-0.0033	-302.82	1.00
MOUNT 4	-0.0033	-302.82	1.00
CAT CC	-0.0036	-302.82	1.09

Constrained Case – LMP Contour Map



Questions?

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