Item 5: A Control Room View of the ERCOT Grid

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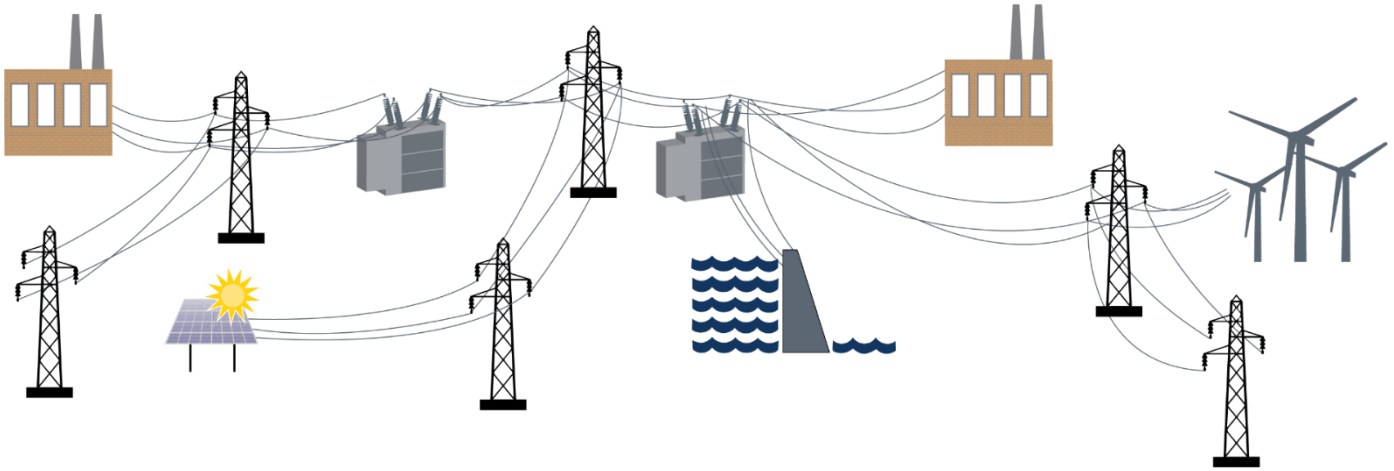
Board of Directors Meeting

ERCOT Public
April 19, 2016

Control Room Information Sources



~50,000 Breakers/Switches

~100,000 Ratings

514 Thermal Units

~1,300 Transformers

~11,000 Wind Turbines

~46,000 Miles Transmission

> 117,000 Outages Annually

208 QSEs

> 93,000 Telemetry Signals

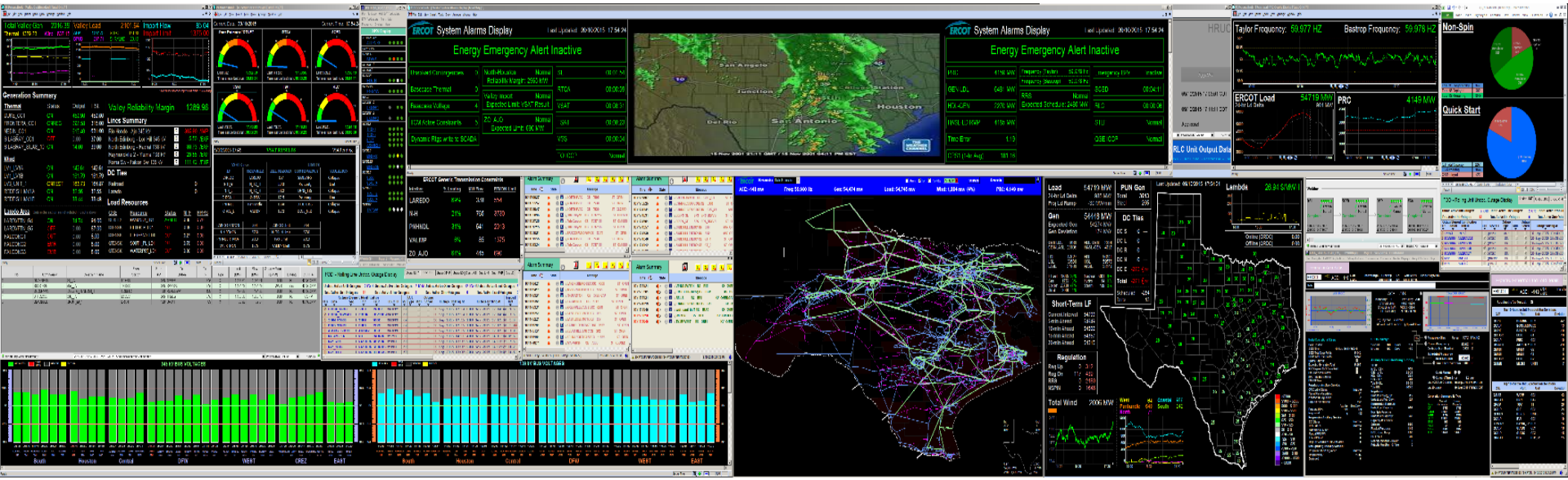
22 TSPS

> 7,500 Modeling Attributes

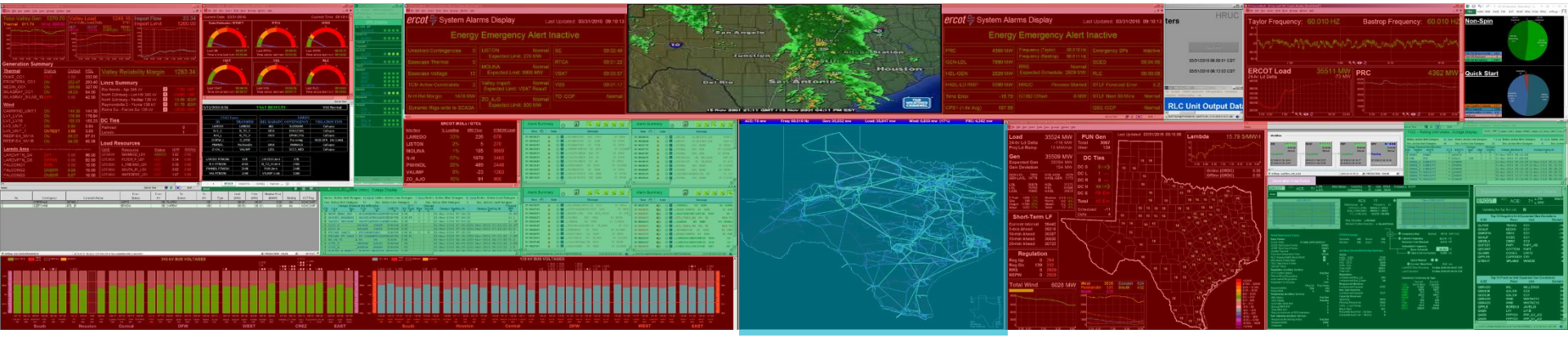
Operator

Control Room Displays

- Tremendous amount of information to manage
- Limited Real Estate



Investment in New Reliability Tools



Standardized Display Building Software

- Enhances the ability to customize displays that are dynamically updated by the underlying model
- Adopts an industry standard display building process
- More secure for the production environment while allowing easier access for users

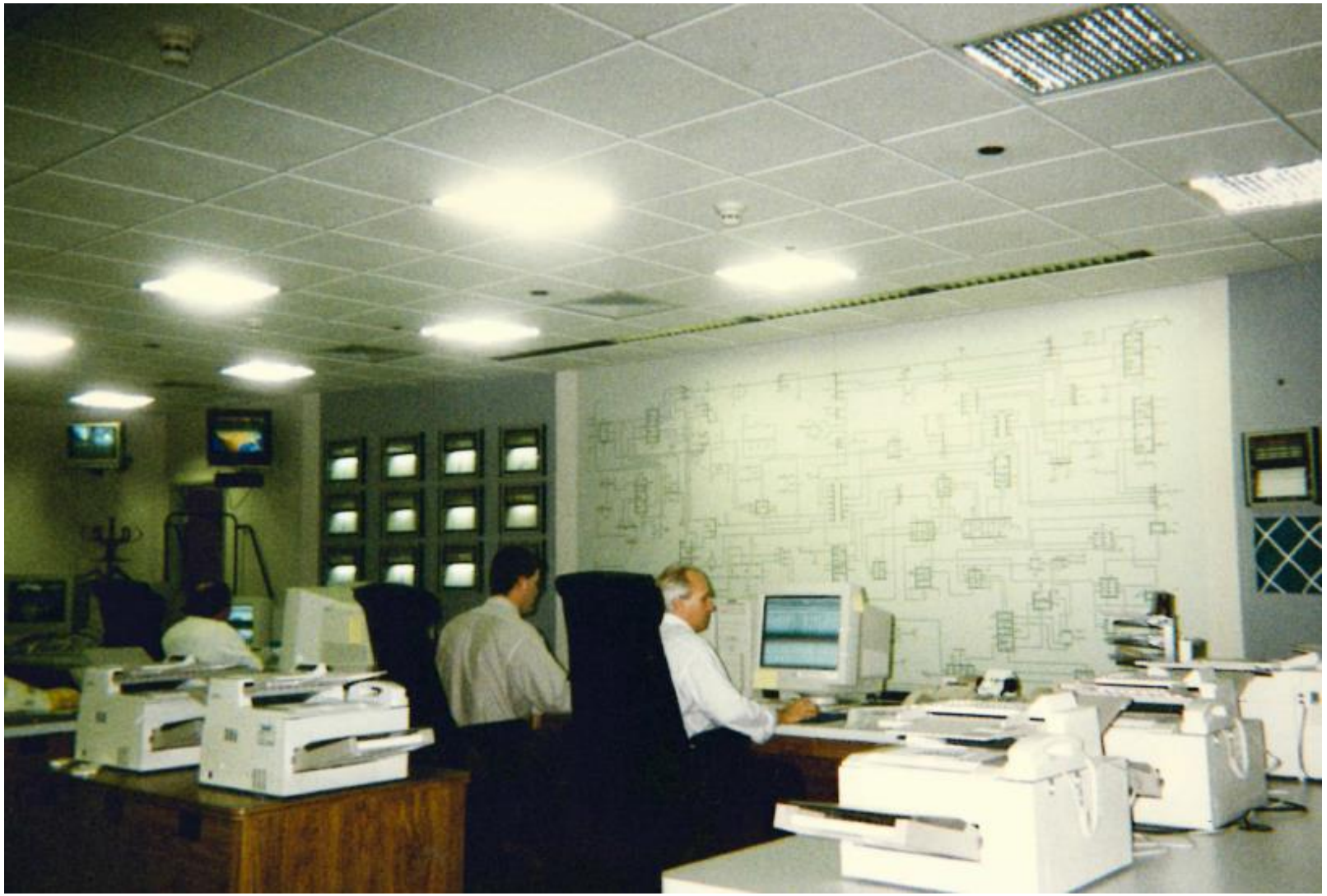
EMS Upgrade

- Final stages of testing of four year project that started in 2013
- Deployment in May/June 2016
- Includes many displays that are unique to ERCOT

Macomber Map

- Code was open-sourced in December 2013
- Numerous companies have provided significant improvements in the code, including SPP
- ERCOT is working on deploying selected improvements in our Control Room and training simulations

ERCOT Control Room circa 2000



ERCOT Control Room 2016

Display Principles

- Careful selection of information to be displayed
  - Good indicators of system performance and critical functions
  - Details available behind the indicators
- Logical and consistent alarming and conditional formatting
- Compilation of related data from multiple source systems
- Clearly defined division of responsibilities

Division of Responsibility - Control Room Desks

- Real-Time Desk
- Transmission and Security Desk
- Resource Operations Desk
- Shift Engineer
- Shift Supervisor
- DC Tie Desk
- Reliability Unit Commitment Desk
- Renewables Desk

Real-Time Desk

Real-Time Desk

- Functions

- Ensures that Frequency within the ERCOT System remains within the tolerances specified by the Protocols and NERC

- Monitors the health of the Security-Constrained Economic Dispatch (SCED) application and validates the reasonableness of the solution

- Verifies the quality of load forecast data and switches sources when necessary

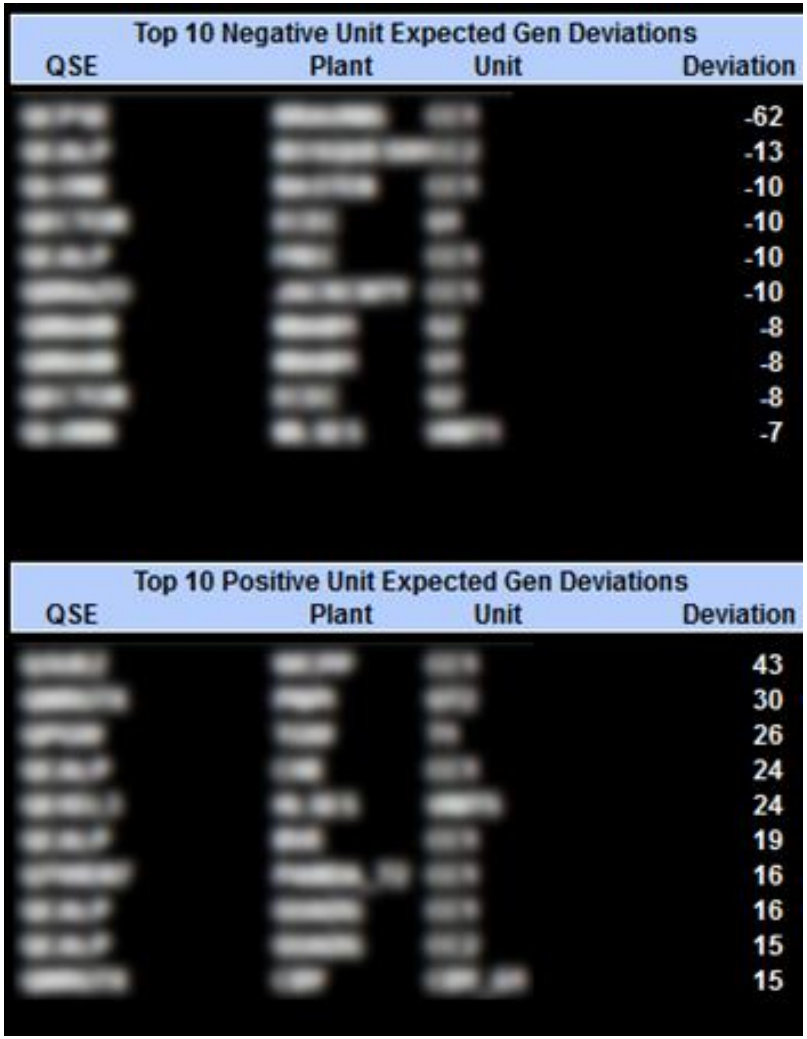
- Challenge

- Managing the large number of Resource changes that can occur during the morning and evening peaks

Real-Time Desk - *tools and displays*

Top 10 Deviations Display

- Lists Resources with largest deviation between MW output and SCED base point
- Quickly highlights Resources potentially affecting frequency



Top 10 Negative Unit Expected Gen Deviations

QSE	Plant	Unit	Deviation
[redacted]	[redacted]	[redacted]	-62
[redacted]	[redacted]	[redacted]	-13
[redacted]	[redacted]	[redacted]	-10
[redacted]	[redacted]	[redacted]	-10
[redacted]	[redacted]	[redacted]	-10
[redacted]	[redacted]	[redacted]	-10
[redacted]	[redacted]	[redacted]	-8
[redacted]	[redacted]	[redacted]	-8
[redacted]	[redacted]	[redacted]	-8
[redacted]	[redacted]	[redacted]	-7

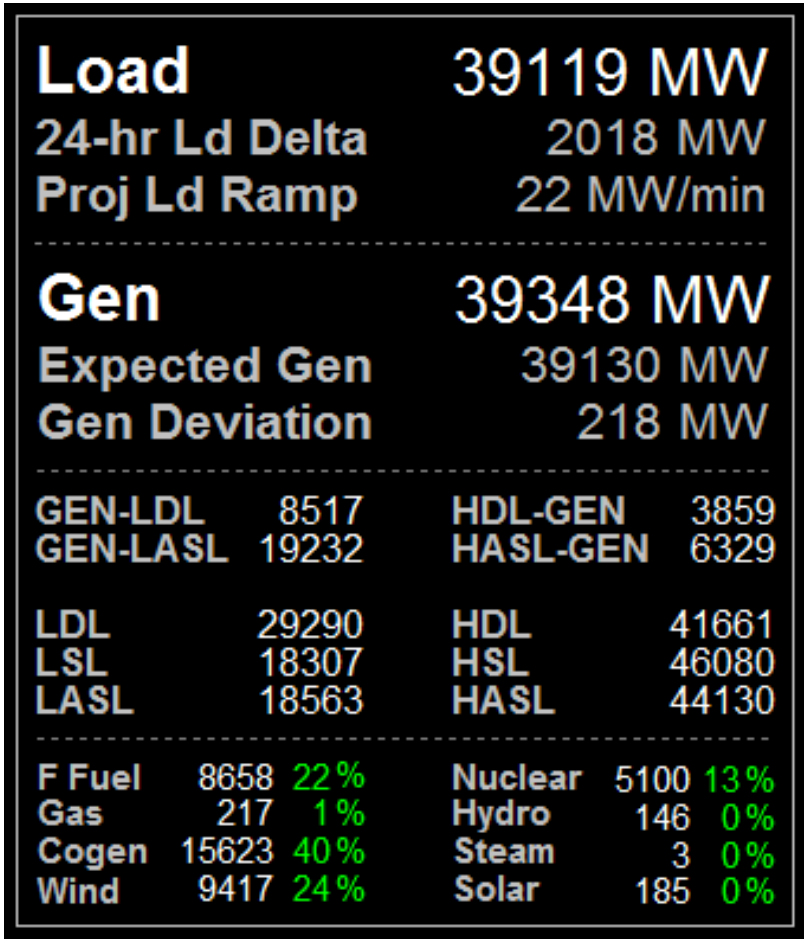
Top 10 Positive Unit Expected Gen Deviations

QSE	Plant	Unit	Deviation
[redacted]	[redacted]	[redacted]	43
[redacted]	[redacted]	[redacted]	30
[redacted]	[redacted]	[redacted]	26
[redacted]	[redacted]	[redacted]	24
[redacted]	[redacted]	[redacted]	24
[redacted]	[redacted]	[redacted]	19
[redacted]	[redacted]	[redacted]	16
[redacted]	[redacted]	[redacted]	16
[redacted]	[redacted]	[redacted]	15
[redacted]	[redacted]	[redacted]	15

Real-Time Desk - *tools and displays*

Load and Generation Details Display

- Lists key calculations comparing current values to forecasted values
- Highlights potential shortages in SCED dispatch



Transmission and Security Desk

Transmission and Security Desk

- Functions

- Analyzes base case and post-contingency constraints and takes actions to maintain system reliability

- Responsible for ensuring the ERCOT system is operated so that instability, uncontrolled separation, or cascading outages will not occur

- Updates stability limits for all ERCOT Generic Transmission Constraints (GTCs) every 10 minutes

- Challenge

- Transmission Security operators are responsible for updating the limit for each GTC, monitoring the flow on each GTC, and activating the constraint when the flow approaches the stability limit.

Transmission and Security Desk - *tools and displays*

Interconnection Reliability Operating Limits (IROL)/GTC Summary display

- Overview of current flows and limits on all ERCOT GTCs
- Gives operator alarms when flow approaches the limit

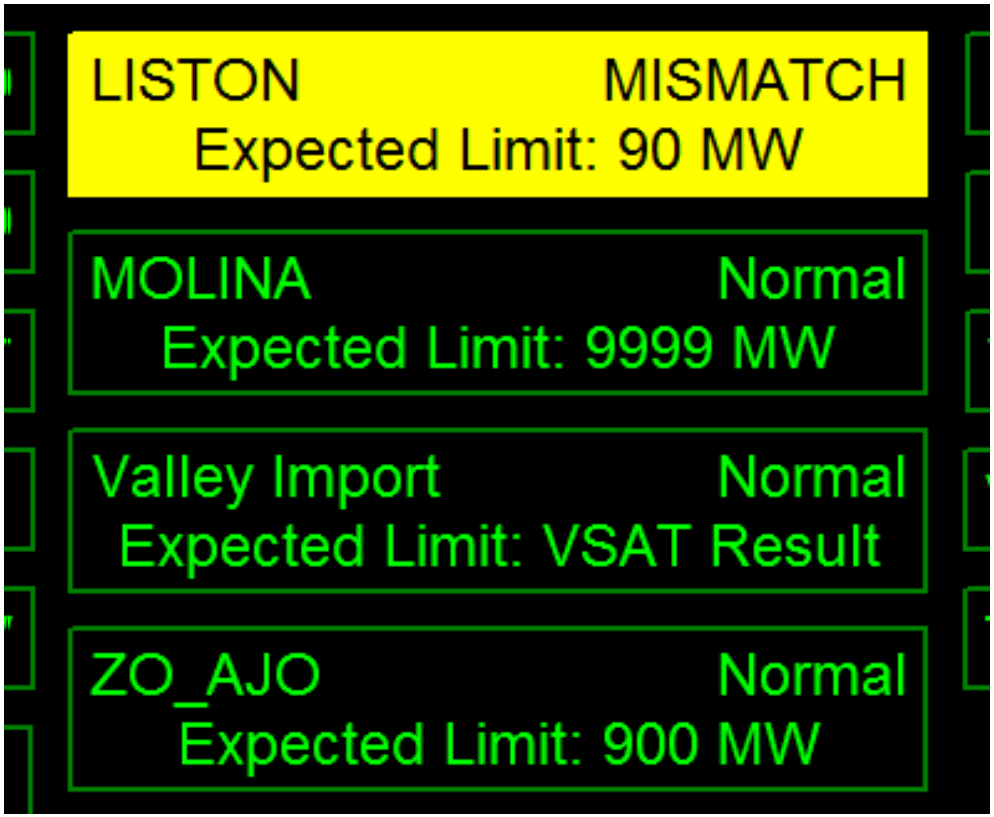
ERCOT IROLs / GTCs

Interface	% Loading	MW Flow	RTMONI Limit
LAREDO	33%	222	680
LISTON	82%	220	270
MOLINA	2%	194	9999
N-H	52%	1619	3105
PNHNDL	3%	300	9999
VALIMP	38%	500	1309
ZO_AJO	56%	502	900

Transmission and Security Desk - *tools and displays*

Video Wall Alarms

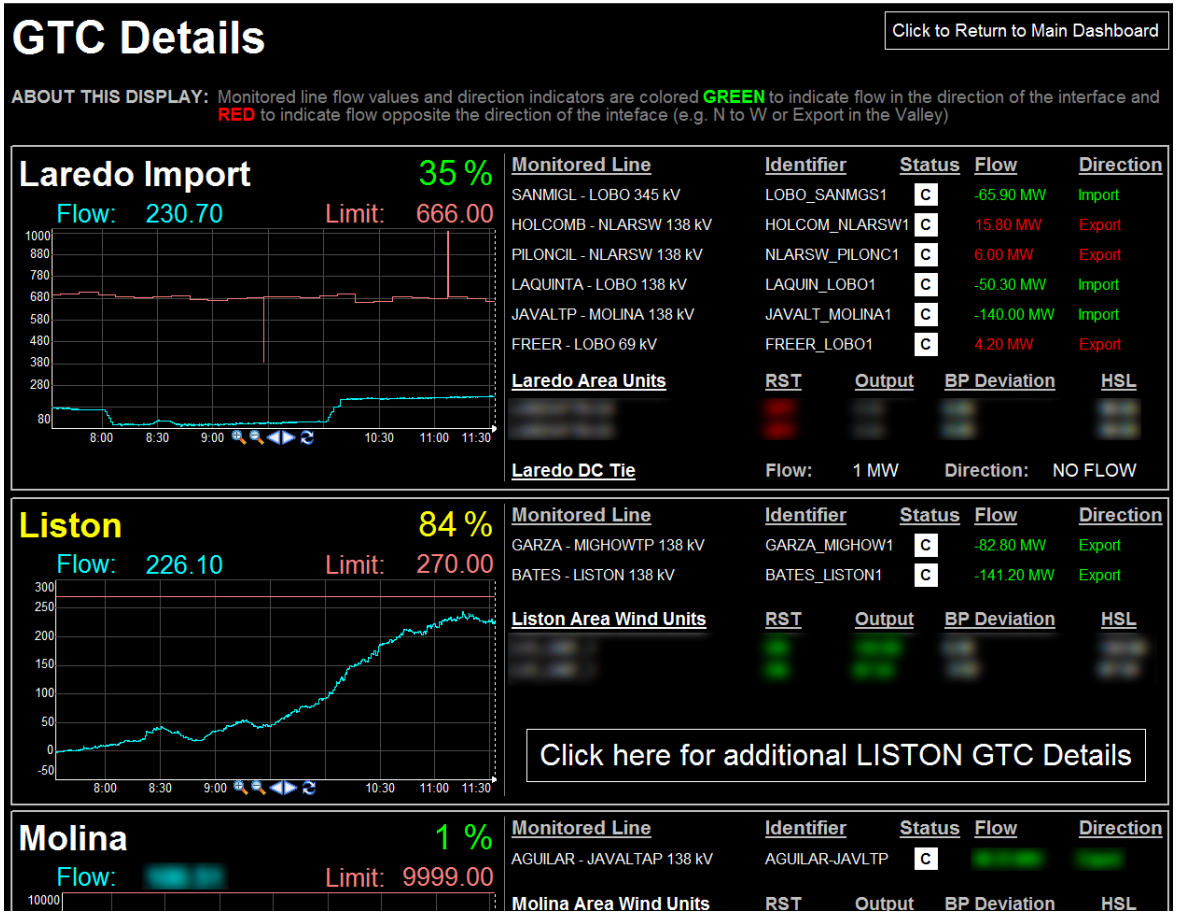
- Operator see alarms when system topology affecting a GTC changes



Transmission and Security Desk - *tools and displays*

IROL/GTC Details display

- Drill-down view gives operator information on all lines in the GTC
- Gives information on other relevant equipment such as nearby generation and DC Ties



Resource Operations Desk

Resource Operations Desk

- Functions

- Monitors Ancillary Service levels and executes a Supplementary Ancillary Services Market (SASM) when necessary
- Deploys and recalls reserves as system requirements change
- Manages Planned, Maintenance, and Forced outages for generation resources

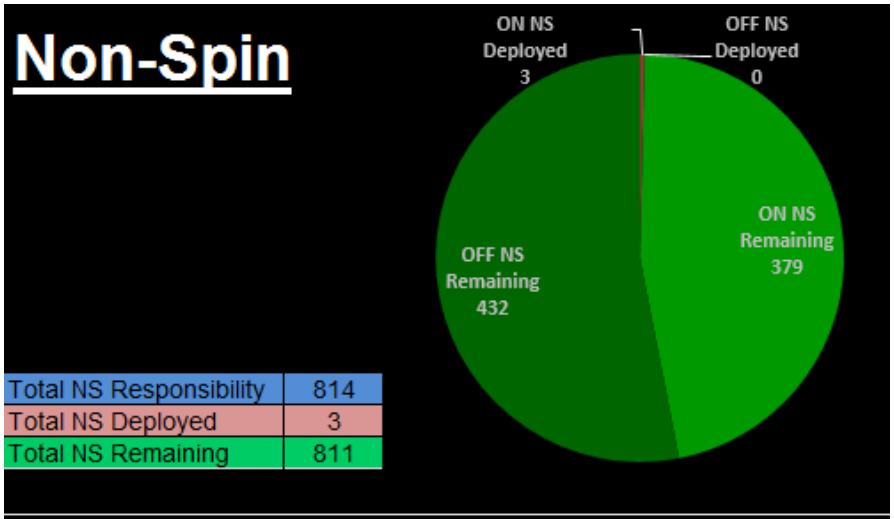
- Challenge

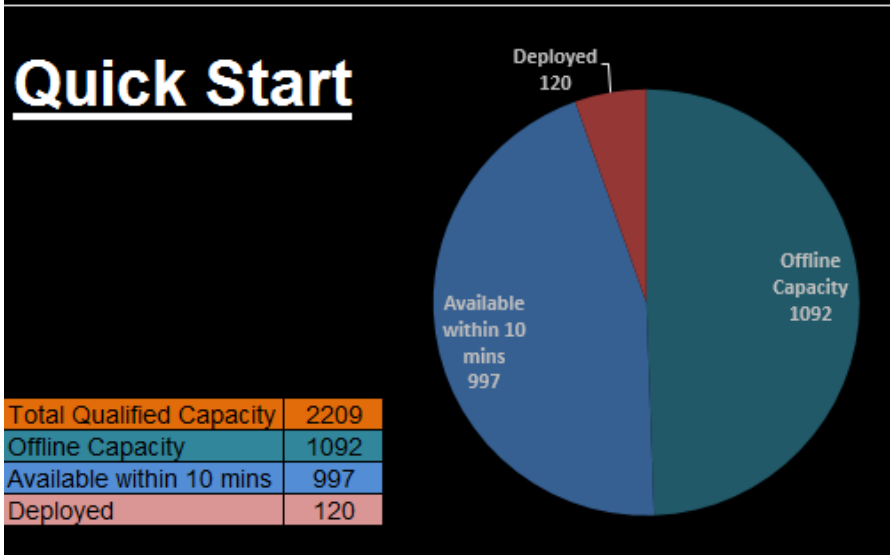
- Continuous monitoring of Ancillary Service levels to ensure all obligations are met

Resource Operations Desk - *tools and displays*

Quick Start/Non-Spin Graphs

- Graphical overview of current Quick Start and Non-Spin capacity
- Indicates what is immediately available and what has already been deployed

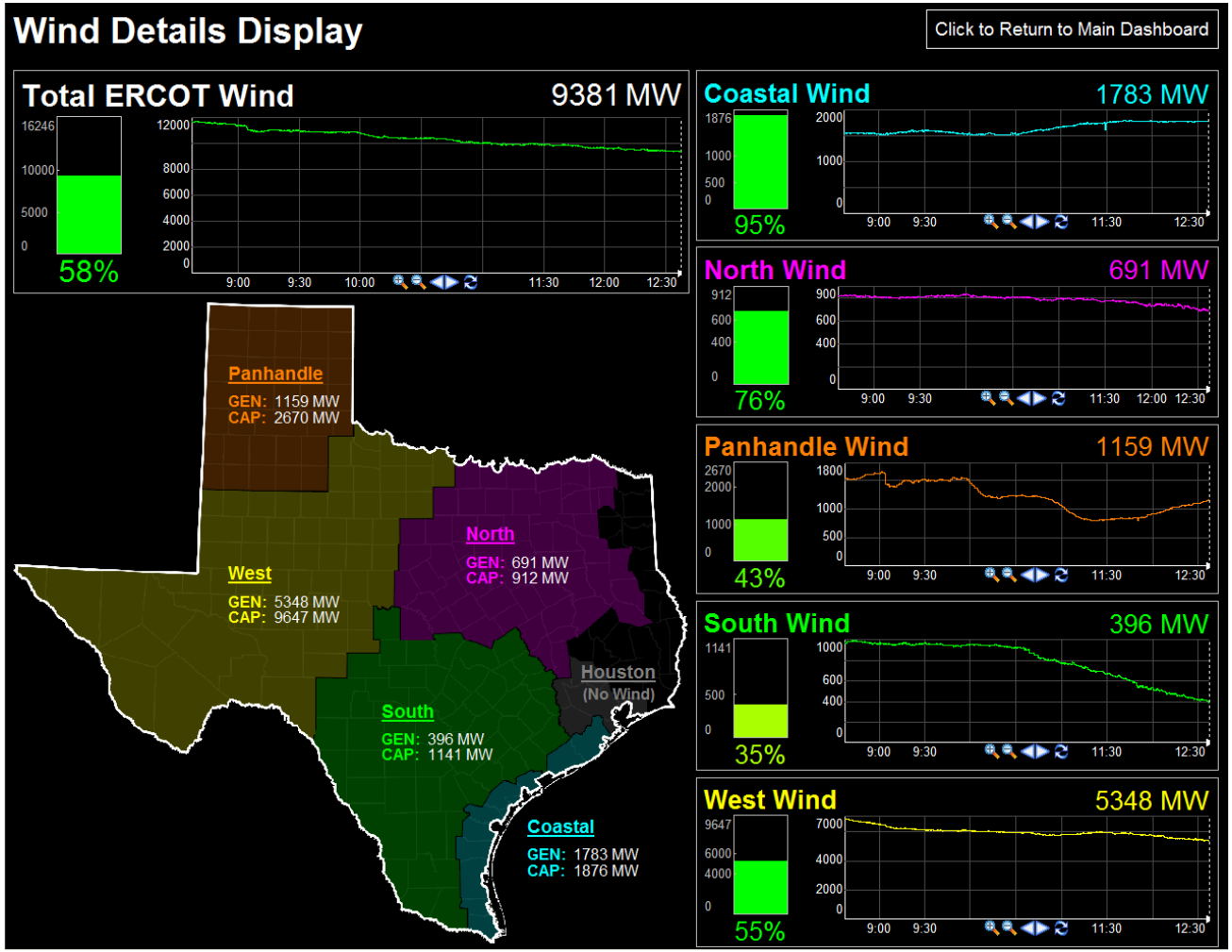




Resource Operations Desk - *tools and displays*

Wind Details

- Provides the operator with breakdown of wind generation by zone
- Allows the operator to visualize current wind generation trends



Shift Engineer

Shift Engineer

- Functions

- Works closely with the ERCOT Control Room System Operators providing around-the-clock support for analysis and system applications

- Develop and author Congestion Management Plans for mitigation of temporary and ongoing grid vulnerabilities

- Gather relevant and accurate information about grid events and communicate that information in a timely manner to Shift Supervisor and engineering support groups

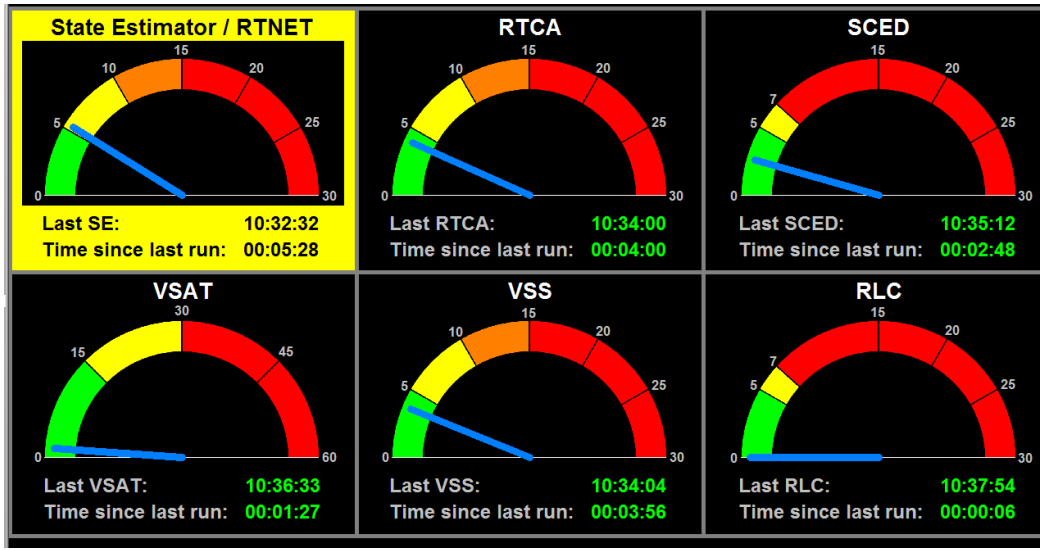
- Challenge

- Support Control Room applications and provide detailed engineering studies in support of System Operators

Shift Engineer - *tools and displays*

Real Time Sequence Monitor

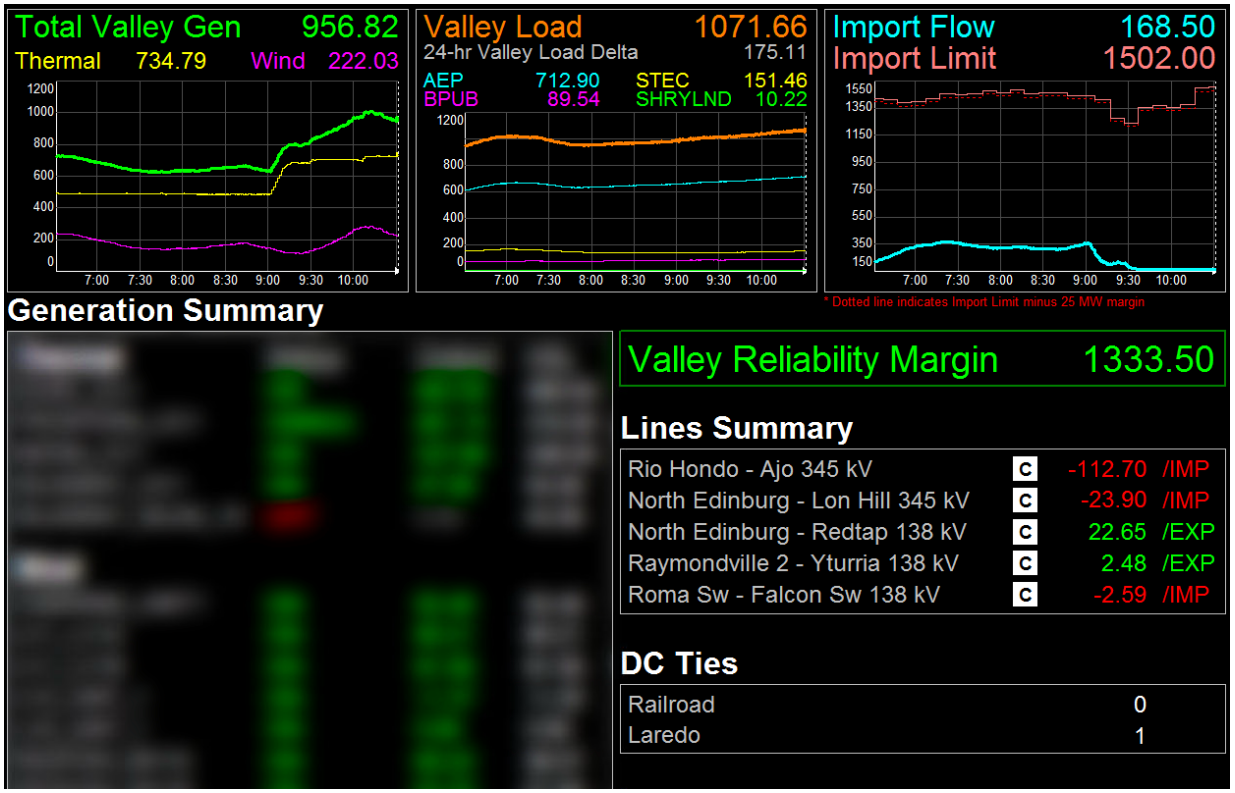
- Summary of real time tools with timer indicating last execution
- Provides the Shift Engineers and operators with alarms when real time applications have not successfully run



Shift Engineer - *tools and displays*

Valley Dashboard

- Overview of current flows on the Valley Import lines
- Overview of TDSP aggregate loads and available generation in the Valley
- Provides Shift Engineers and operators with alarms when import flow approaches the Valley import limit



Shift Supervisor

Shift Supervisor

- Functions

- Monitors the operation of all desks in the Control Room
- Continually reviews and analyzes system security
- Provides the primary point of communication with ERCOT Management and Market Participants

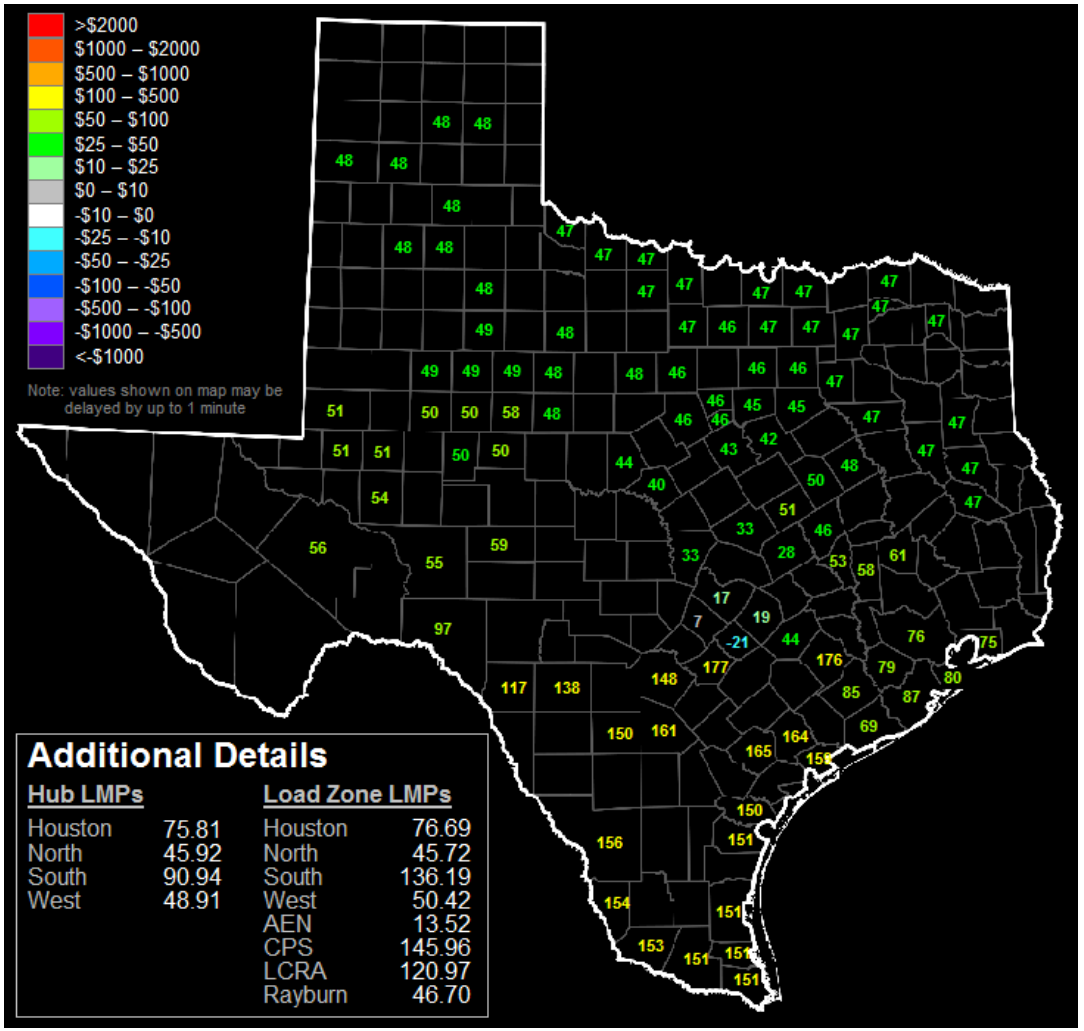
- Challenge

- Maintaining high-level overview knowledge of the system as conditions rapidly change

Shift Supervisor - *tools and displays*

Location Marginal Price Map

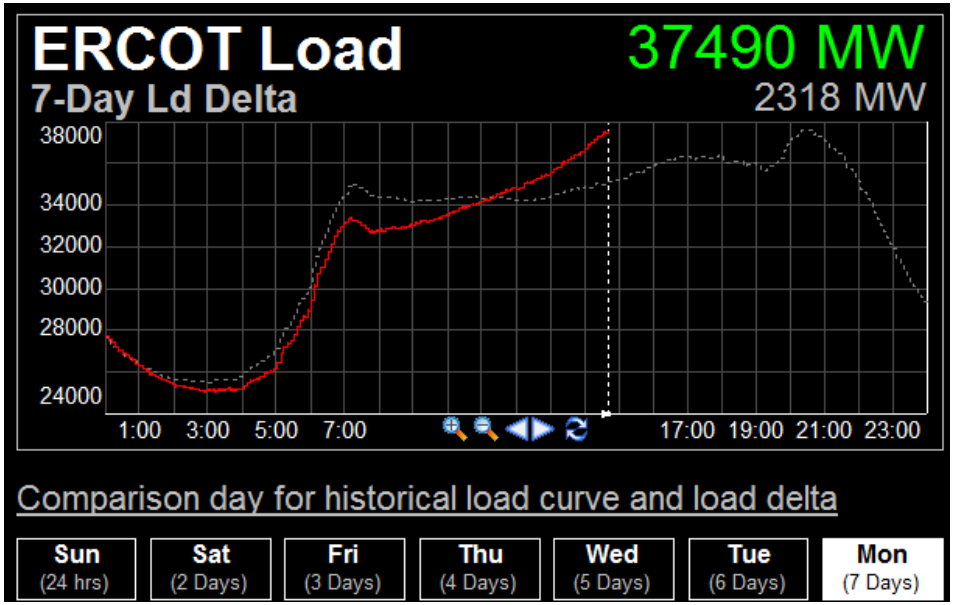
- Overview of current Locational Marginal Pricing by county
- Provides an indication of congestion as seen through price splits between counties



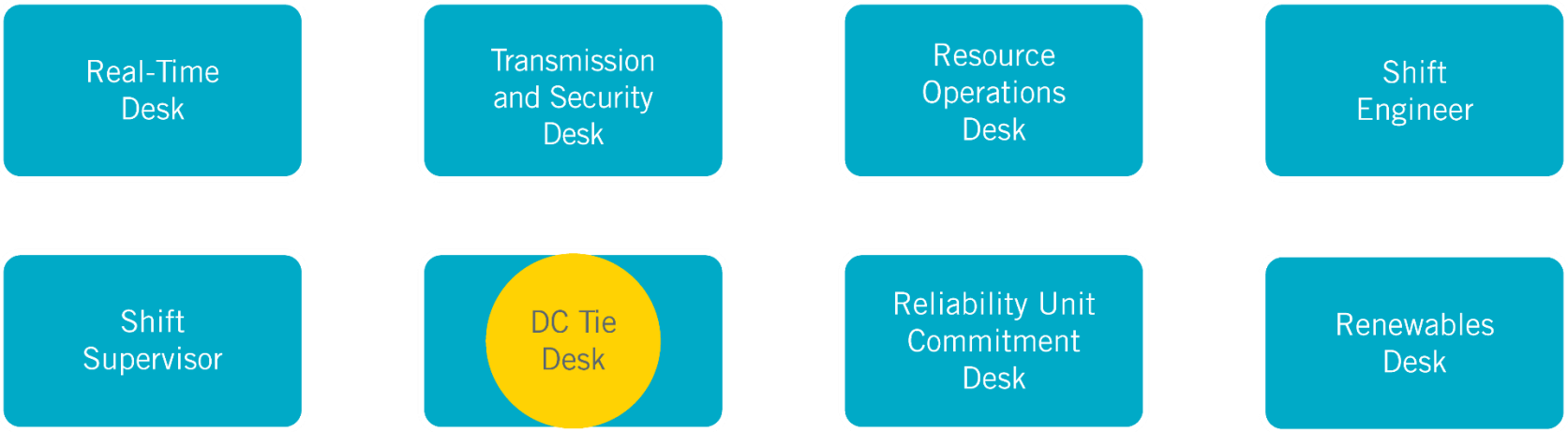
Shift Supervisor - *tools and displays*

ERCOT Load Display

- Provides the Shift Supervisor and Operators with an overview of current system load trend relative to previous operating days



DC Tie Desk


Real-Time Desk
Transmission and Security Desk
Resource Operations Desk
Shift Engineer
Shift Supervisor
DC Tie Desk
Reliability Unit Commitment Desk
Renewables Desk

DC Tie Desk

- Functions

- Schedules and monitors energy transactions into and out of the ERCOT Control Area across the asynchronous DC Ties

- Coordinates the import of emergency energy across the DC Ties into the ERCOT Control Area during Emergency Operations

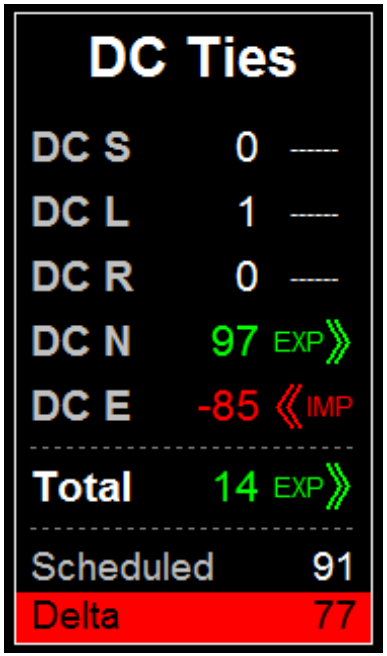
- Challenge

- Prevent the accumulation of Inadvertent Energy by monitoring real-time flows across the DC Ties to ensure they are ramping appropriately and matching scheduled flows.

DC Tie Desk - *tools and displays*

DC Tie Summary

- Overview of real time DC Tie imports and exports
- Alarms when the actual DC Tie total differs significantly from what is scheduled



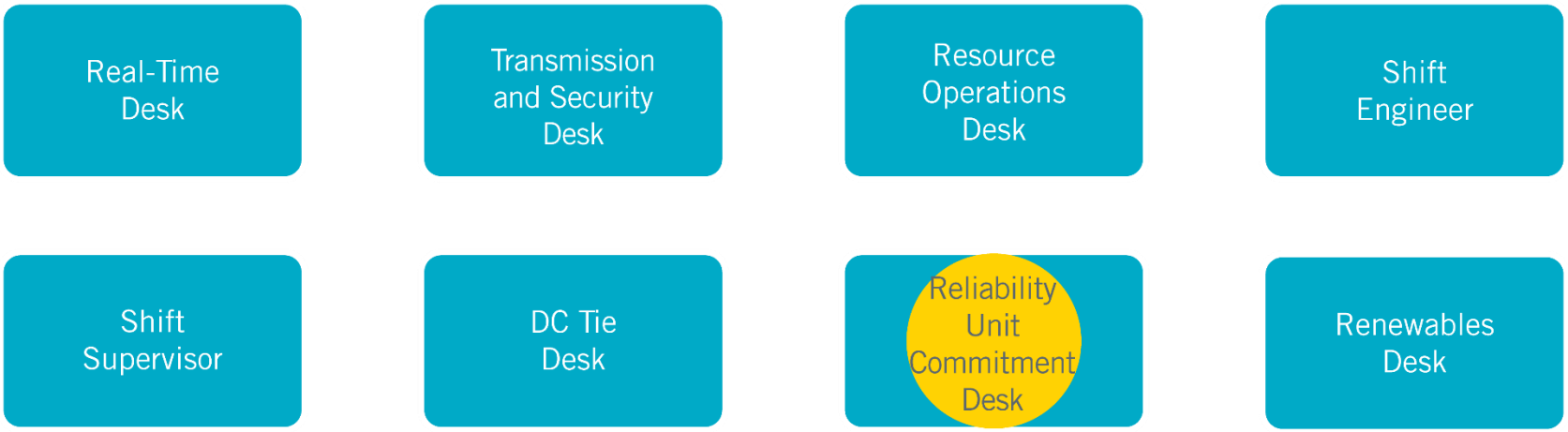
DC Tie Schedules

- Provides the DC Tie Desk operators with a look ahead on upcoming DC Tie schedules

DSI DC Tie Schedule

DC Tie Name	01:00:00 CDT	02:00:00 CDT	03:00:00 CDT	04:00:00 CDT	05:00:00 CDT	06:00:00 CDT	07:00:00 CDT
DC_R	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DC_S	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00	-6.00
DC_L	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DC_E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DC_N	-220.00	-220.00	-220.00	-220.00	-220.00	-220.00	-220.00

Reliability Unit Commitment (RUC) Desk



RUC Desk

- Functions

- Oversees the Weekly Reliability Unit Commitment (WRUC), Day-Ahead Reliability Commitment (DRUC), and Hourly Reliability Unit Commitment (HRUC) processes

- Performs hourly studies to identify potential voltage problems on the ERCOT system

- Responds to QSE inquiries about RUC commitments

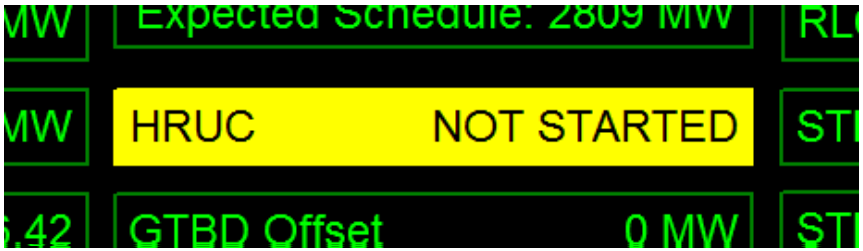
- Challenge

- Maintains the RUC process while monitoring changing system conditions and looking for problems with resource capacity

RUC Desk- *tools and displays*

HRUC System Alarm

- Indicates the status of the HRUC process on the video wall
- HRUC is partially automated
- Gives the operator an alarm when the results of HRUC have not been reviewed and approved
- HRUC must be approved by 50 minutes past the hour
- Also alarms if the automated portion of the HRUC process has not started



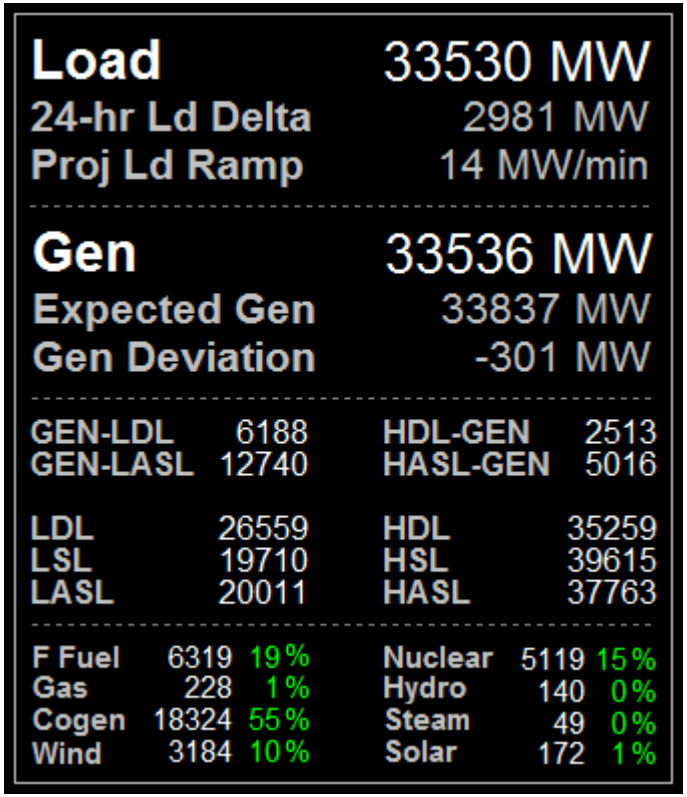
RUC Desk - *tools and displays*

Current Generation/Load Details

- Centralized location for details on generation, reserves, and fuel mix on the video wall

Reserves System Alarms

- Several alarms related to system capacity and reserves



Renewables Desk

Renewables Desk

- Changing resource mix and expanded transmission grid has created more monitoring and voltage control activity
  - Increase in 345-kV circuit miles associated with CREZ
  - Additions to renewable capacity
  - Increased need to coordinate reactive device switching
  - Increased importance of load, wind, and solar forecasting
- As approved in 2015, ERCOT is currently in the process of hiring new staff, building new tools, and analyzing the integration of this desk with the existing desks.

Renewables Desk- *tools and displays*

System Voltage Overview Display

- Gives an overview of voltage levels at some 345 kV and 138 kV busses around the ERCOT system
- Alerts operators when voltage levels are too high or too low
- Indicates what reactive devices can be put in service to help control voltage