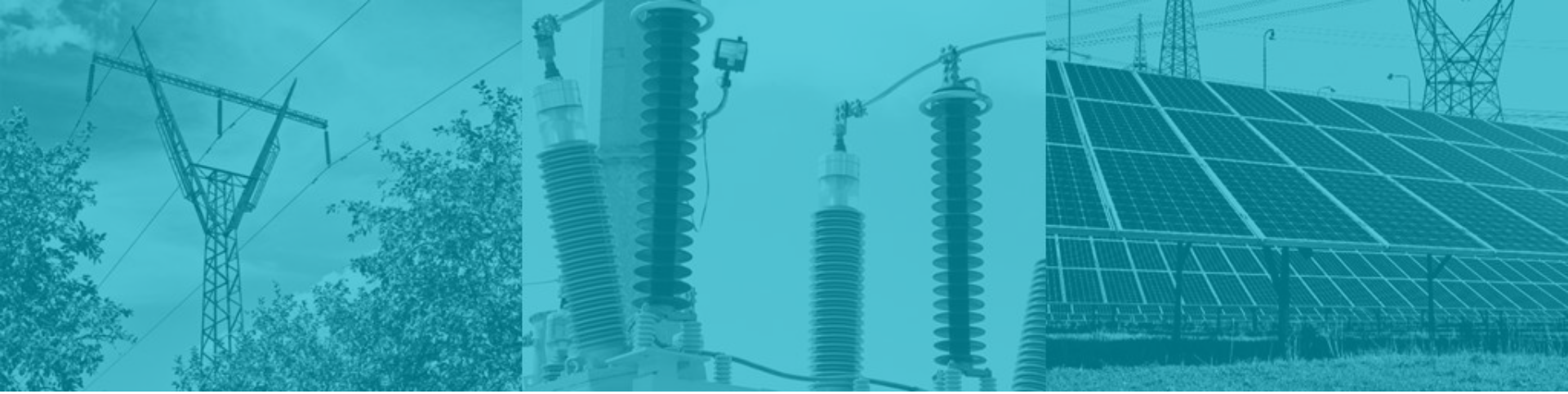


ERCOT Market Education

Resource 301

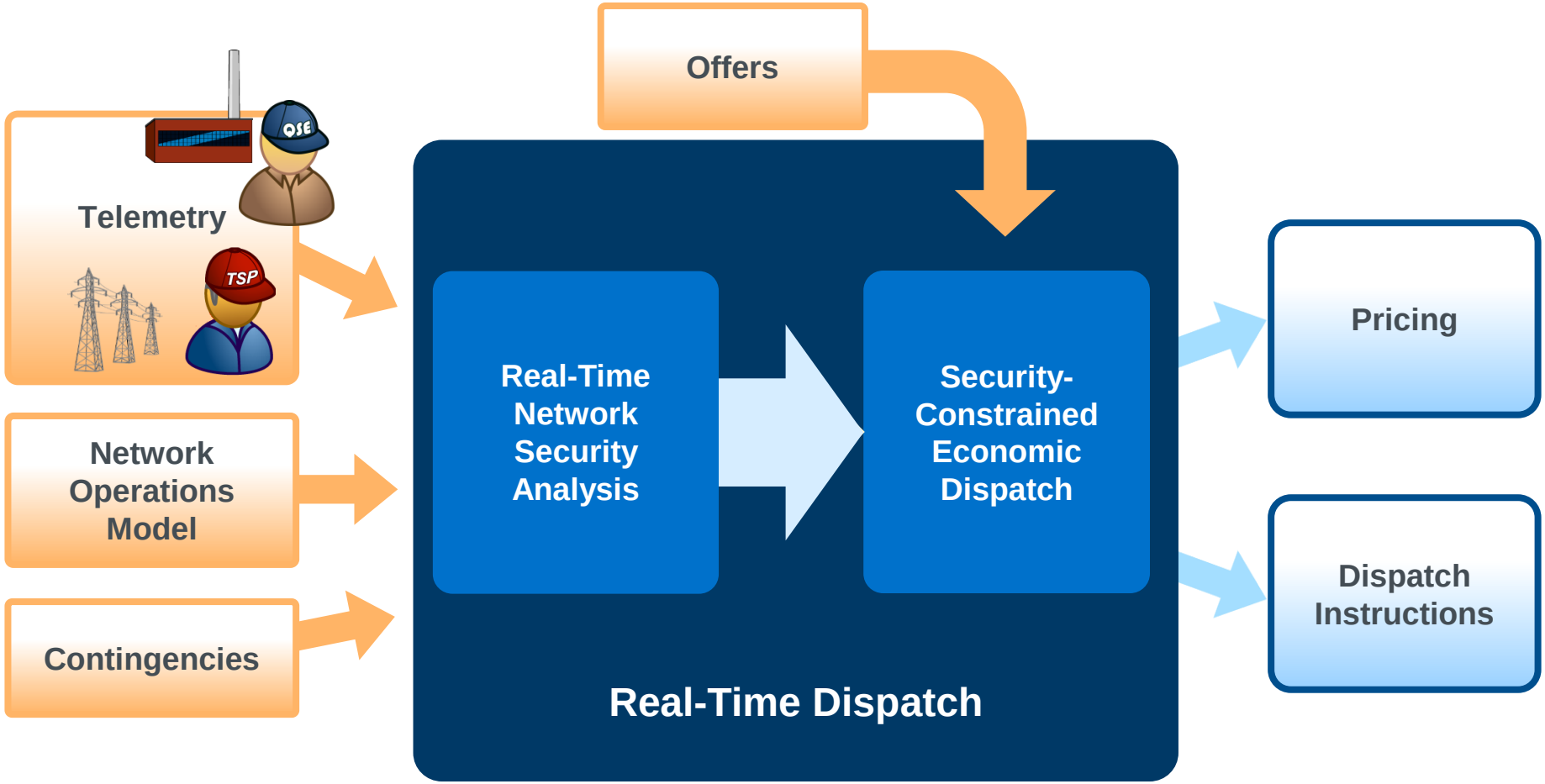
Module 5: Resources in Real-Time Operations

Topics in this module ...

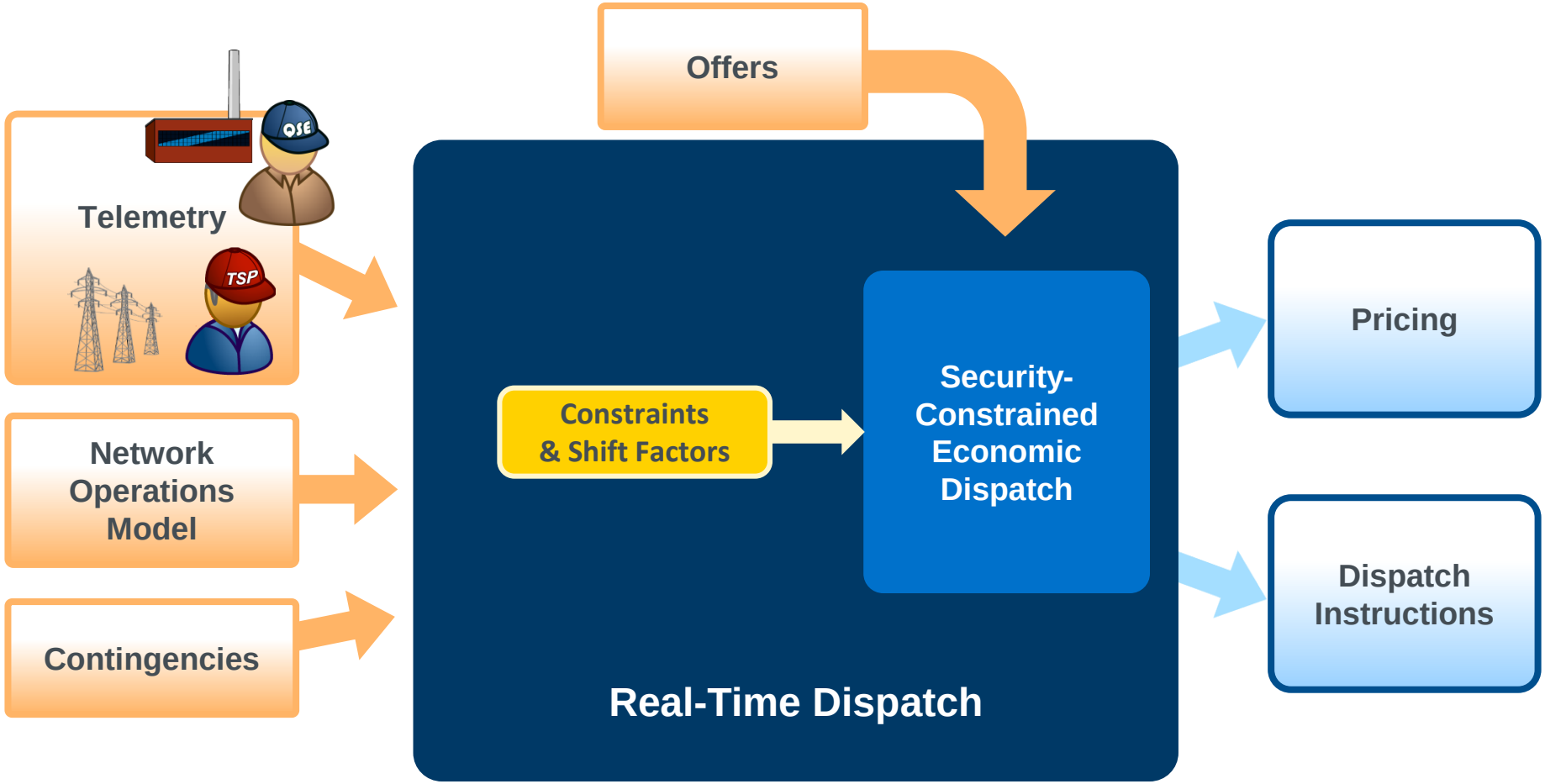
- Real-Time Dispatch Overview and Formation of Dispatch Limits
- The Mind of SCED (Security Constrained Economic Dispatch)
- Load Frequency Control and Primary Frequency Response
- Provision and Deployment of Ancillary Services
- Real-Time Settlements

Real-Time Dispatch Overview
&
Formation of Dispatch Limits

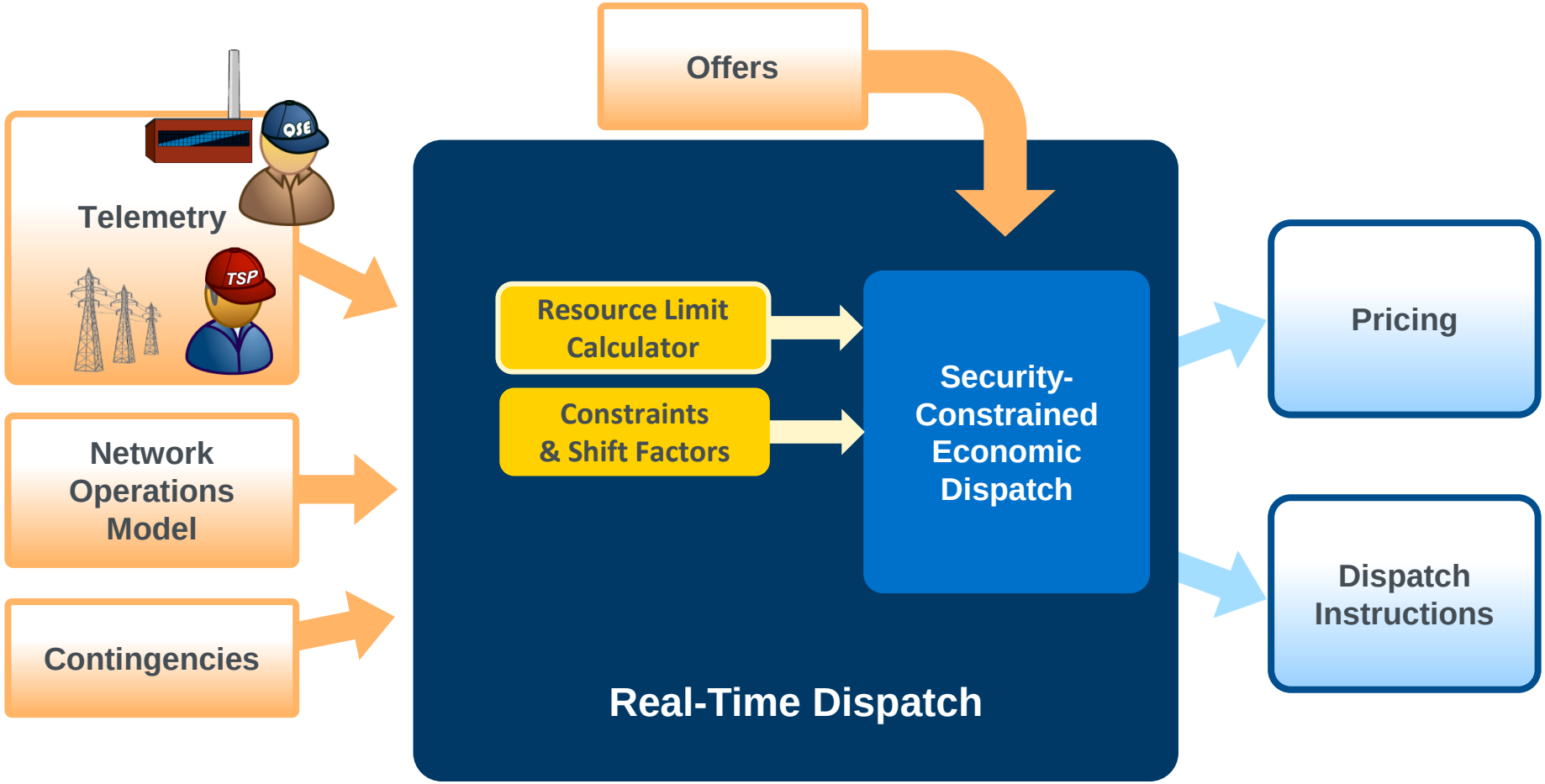
SCED requires multiple inputs



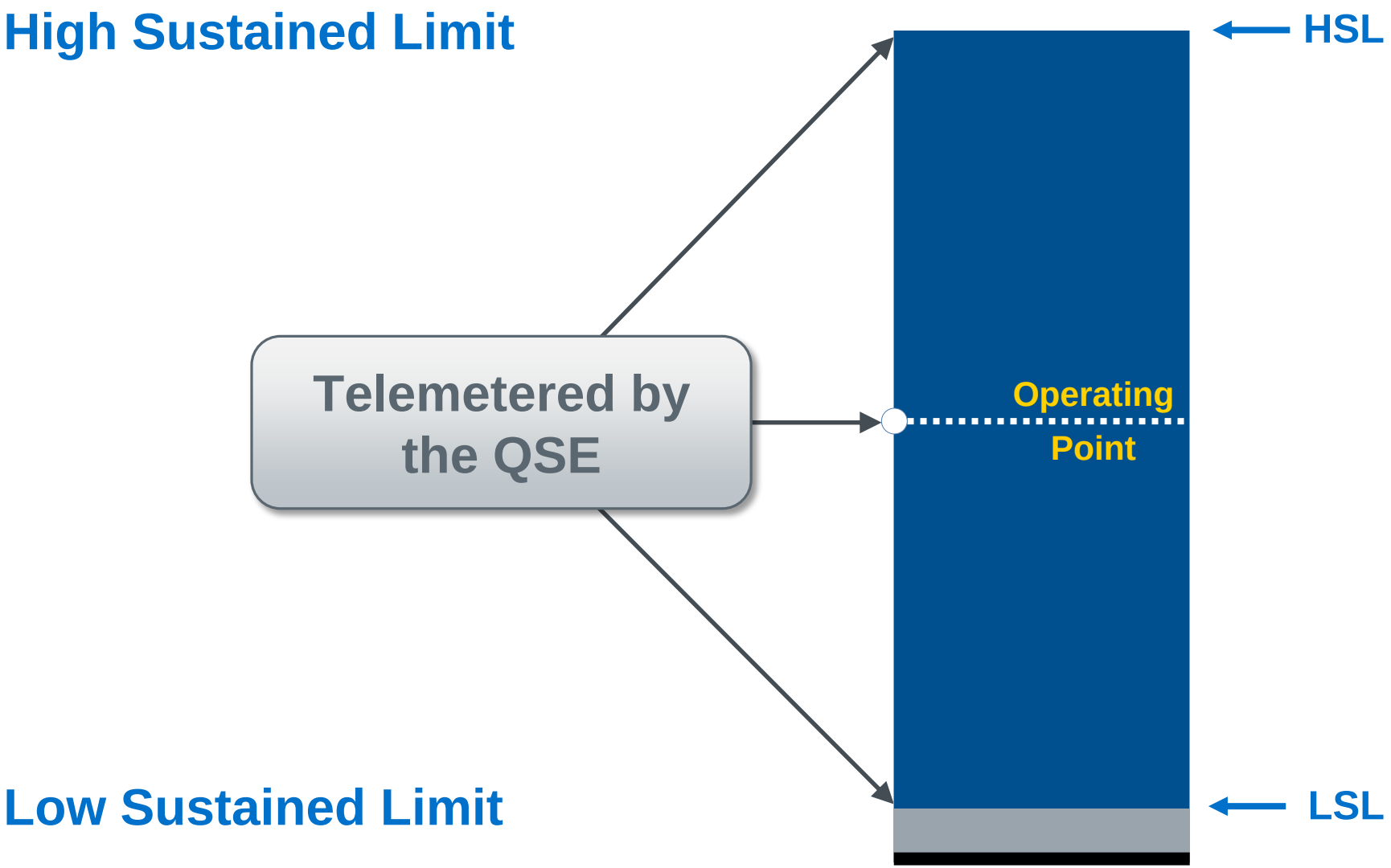
Security Analysis provides Transmission Constraints



Resource Limit Calculator determines Dispatch Limits



Dispatch Limits for Generation Resources

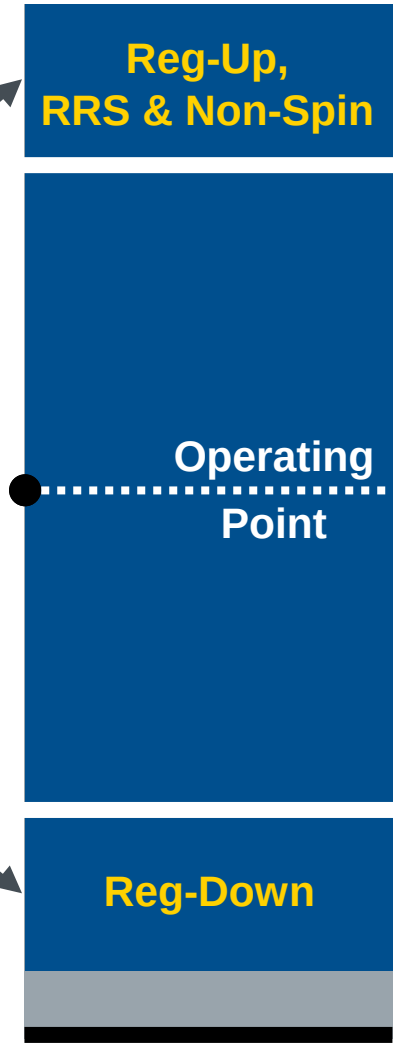


Dispatch Limits for Generation Resources

High Sustained Limit

Telemetered by the QSE

- AS Schedule (RRS & Non-Spin)
- AS Resource Responsibility (Reg)



HSL

LSL

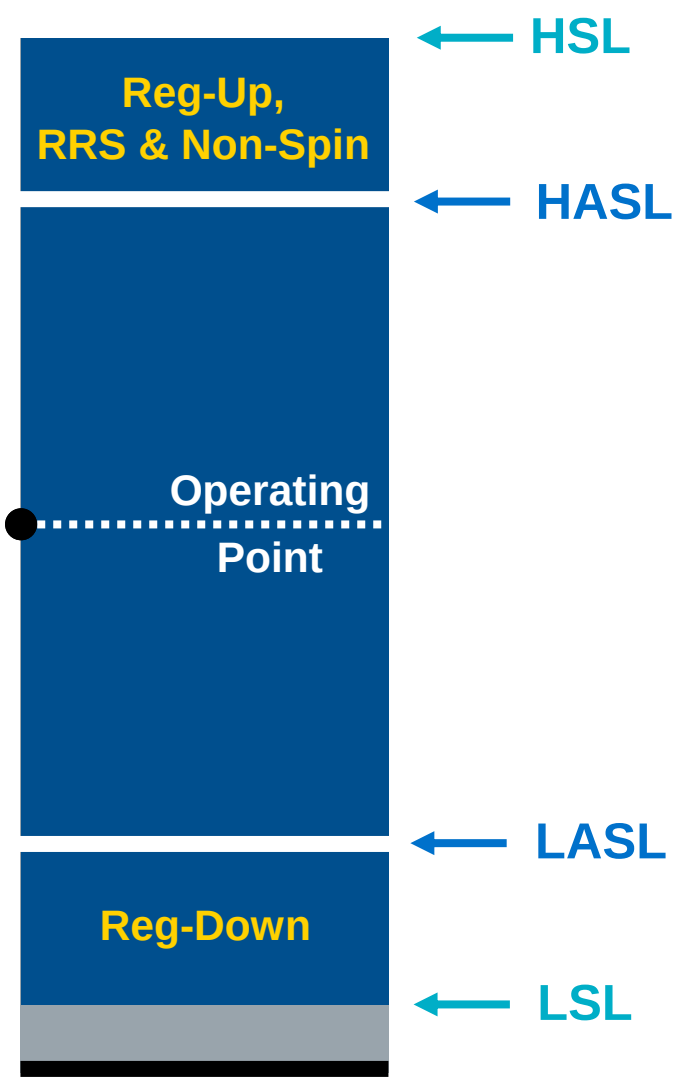
Low Sustained Limit

High Ancillary Service Limit

= HSL – Reg-Up Responsibility
– RRS Schedule
– Non-Spin Schedule

Low Ancillary Service Limit

= LSL – Reg-Down Responsibility



SCED Up Ramp Rate (SURAMP)

= Up Ramp Rate

– (1- RDSDEPLP) * (Reg-Up Resp / 7)

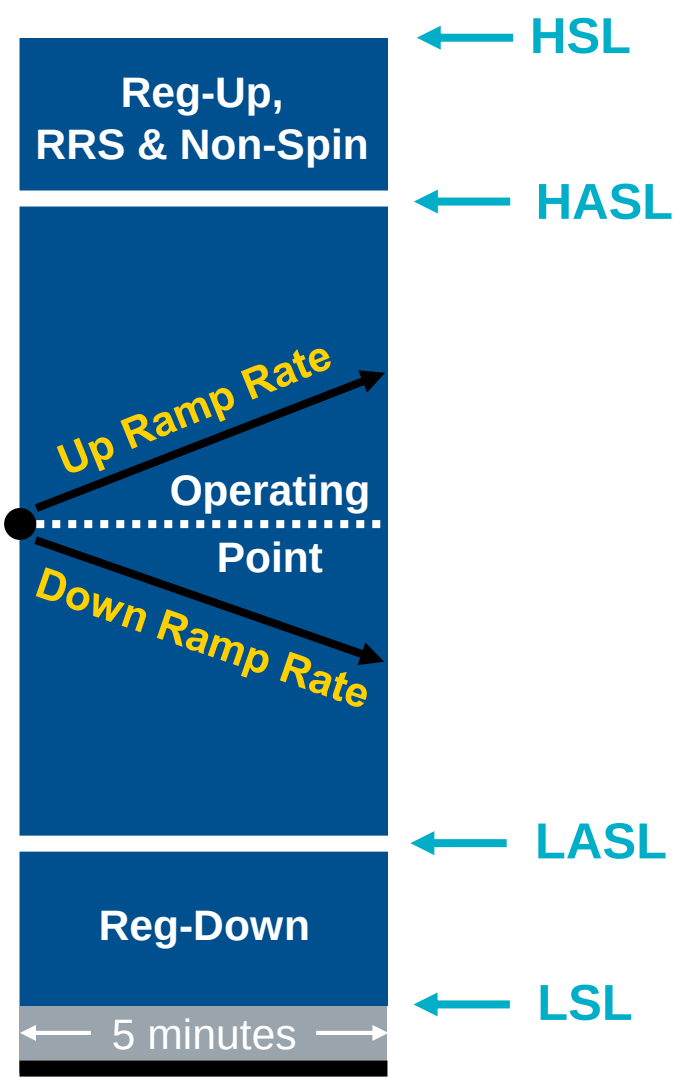
Reg-down Deployment Percentage

SCED Down Ramp Rate (SDRAMP)

= Down Ramp Rate

– (1- RUSDEPLP) * (Reg-Down Resp / 7)

Reg-up Deployment Percentage



High Dispatch Limit

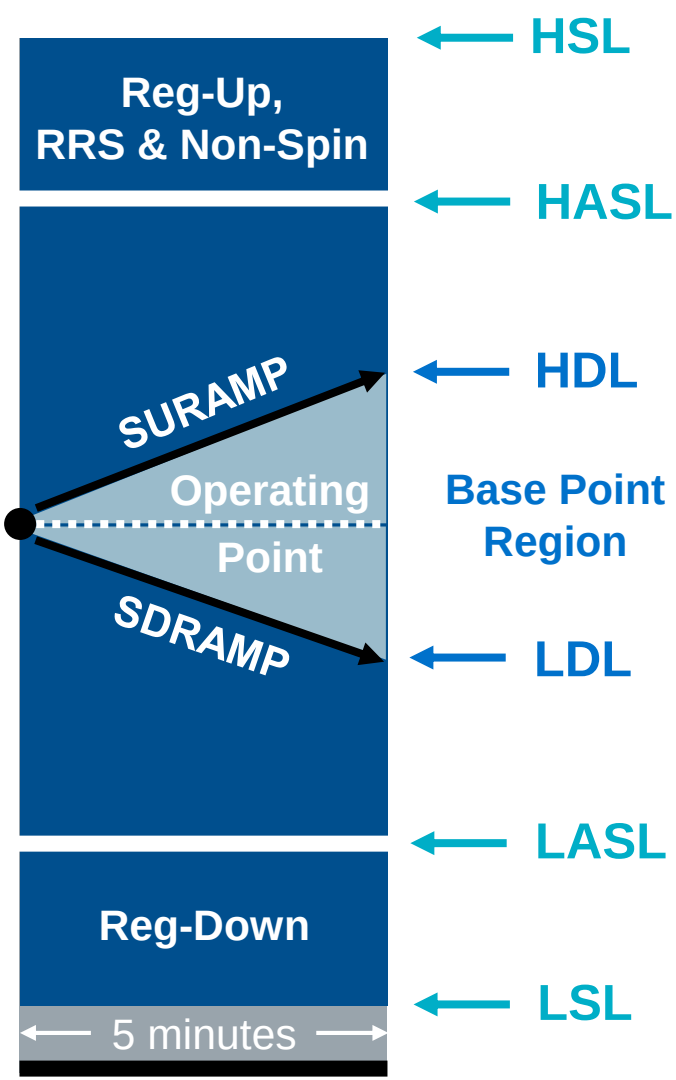
HDL = Operating Point + (SURAMP * 5)

HDL ≤ HASL

Low Dispatch Limit

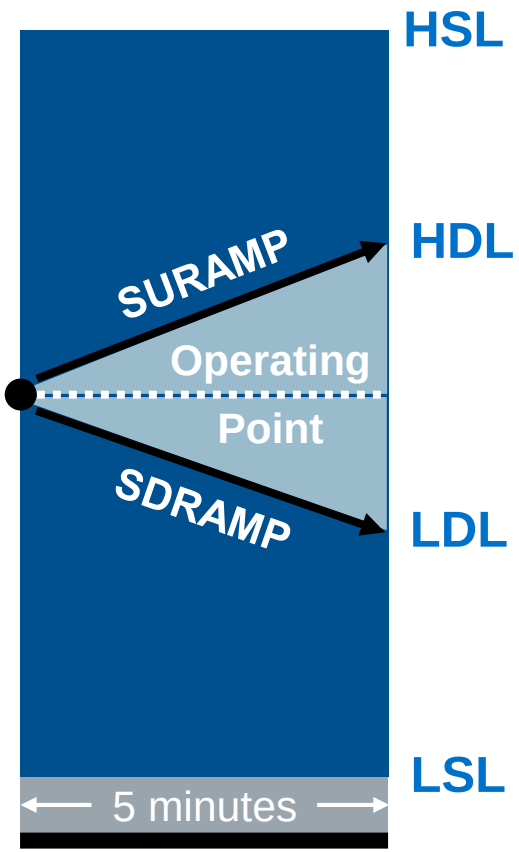
LDL = Operating Point – (SDRAMP * 5)

LDL ≥ LASL



Example 1

Generator is "ON" with current operating point of 150MW



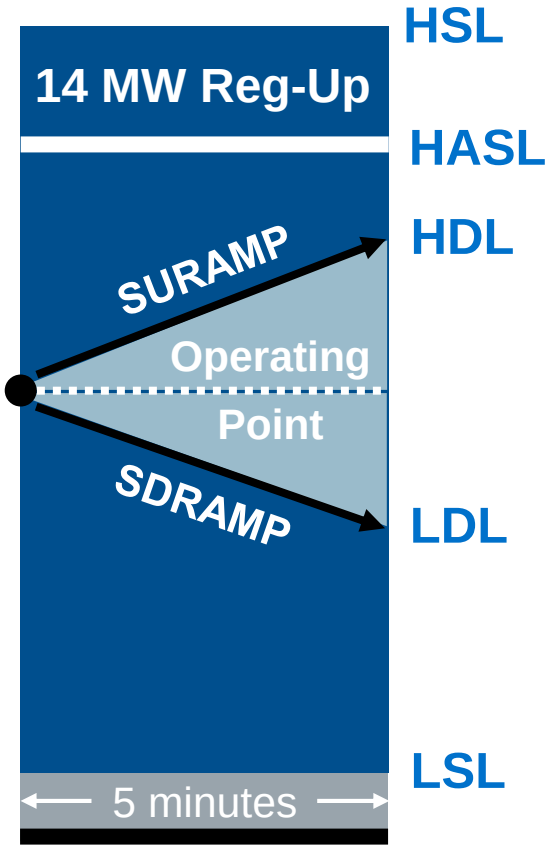
Ramp Rates:

- Normal Up = 3MW/min
- Normal Down = 4MW/min

What are HDL and LDL?

Example 2

Generator is "ONREG" with current operating point of 150MW



Ramp Rates:

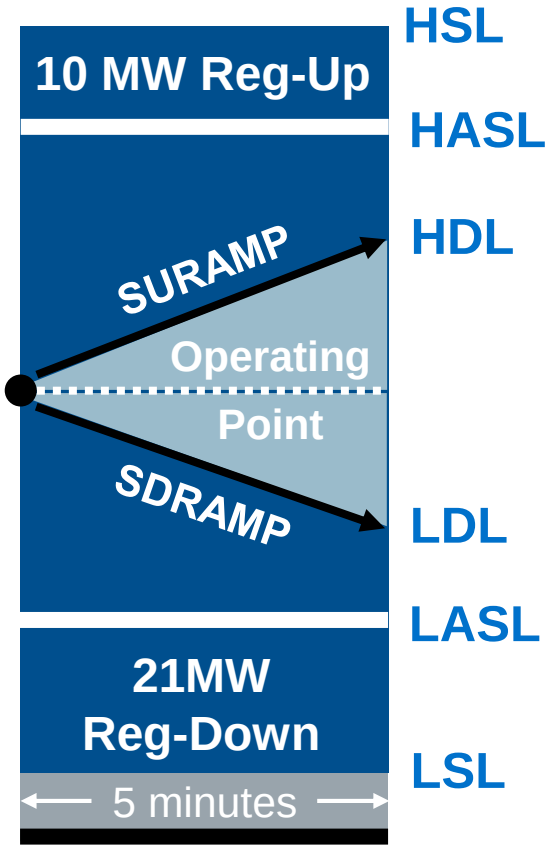
- Normal Up = 3MW/min
- Normal Down = 4MW/min

Reg-Down deployment percentage = 50%

What is HDL?

Example 3

Generator is "ONREG" with current operating point of 150MW



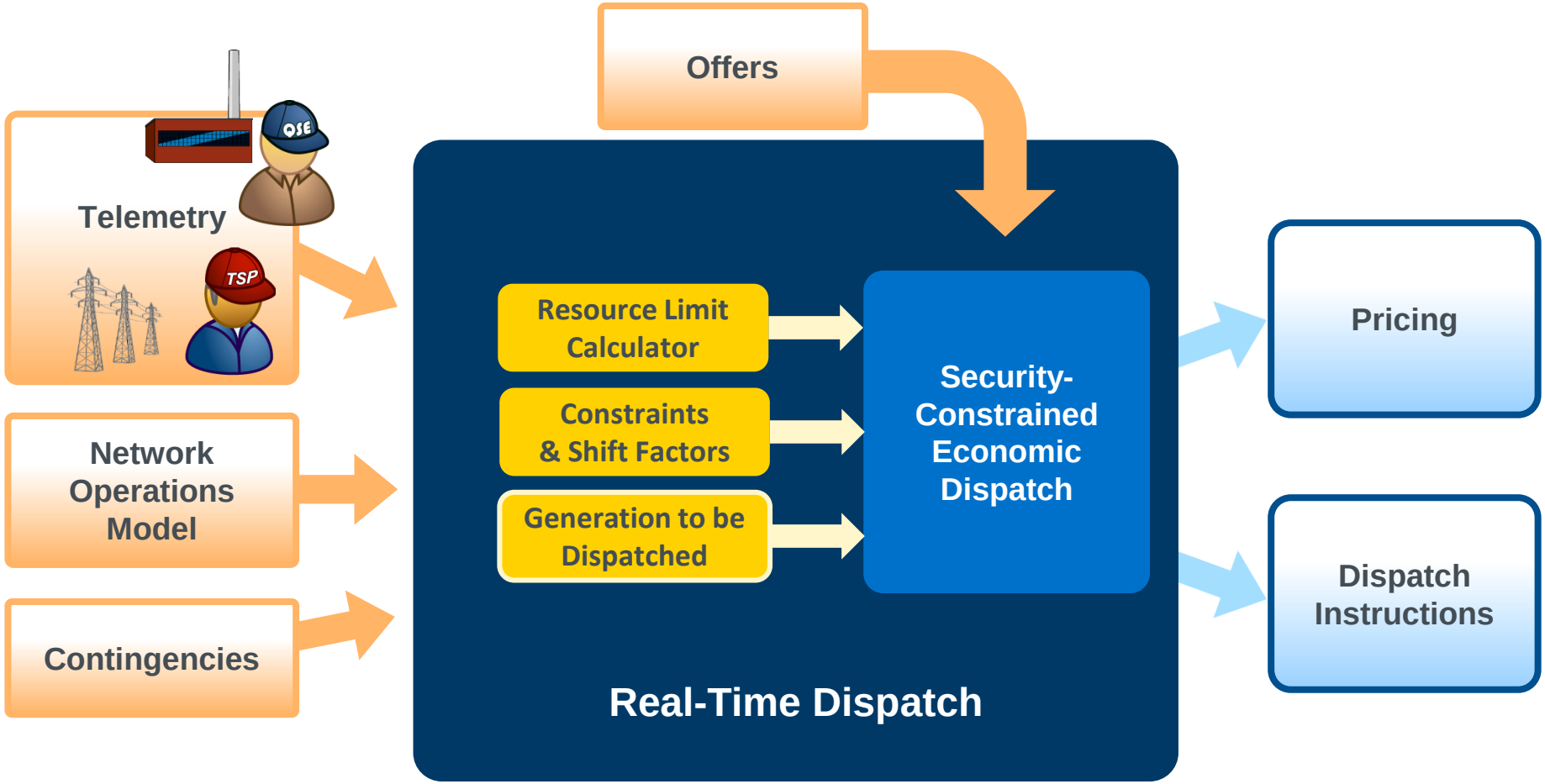
Ramp Rates:

- Normal Up = 3MW/min
- Normal Down = 4MW/min

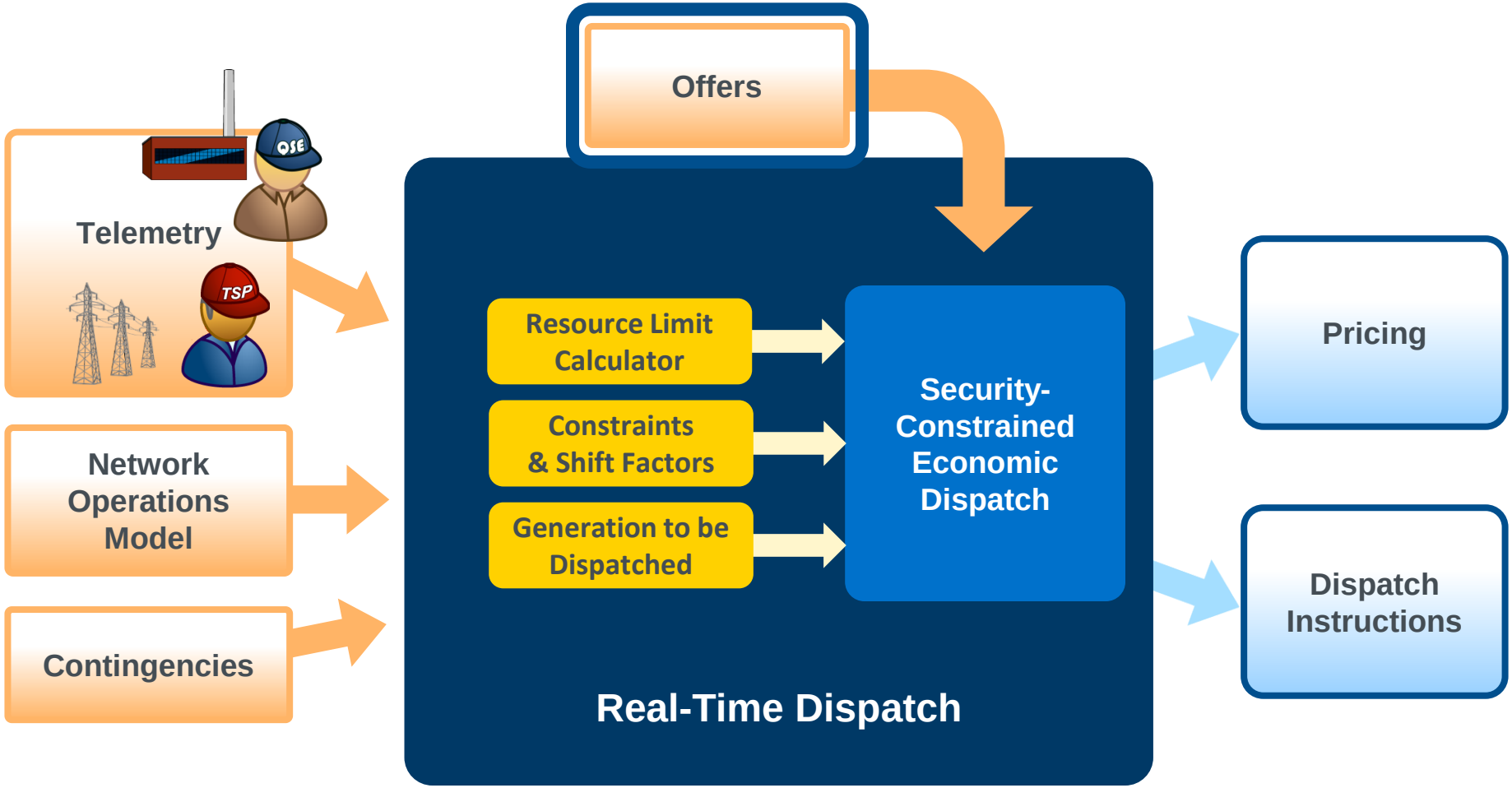
Reg-Up deployment percentage = 0%

What is LDL?

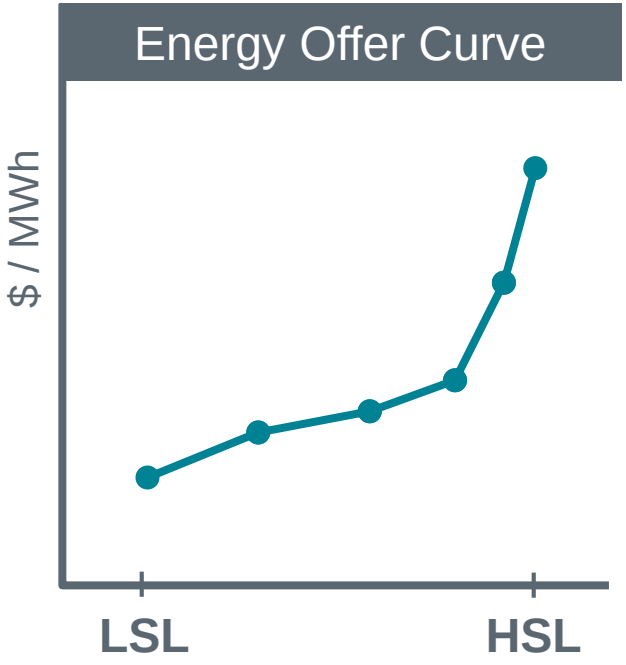
SCED must also have a Power Balance Constraint



Offers allow SCED to achieve economic dispatch



Offer for a Generation Resource



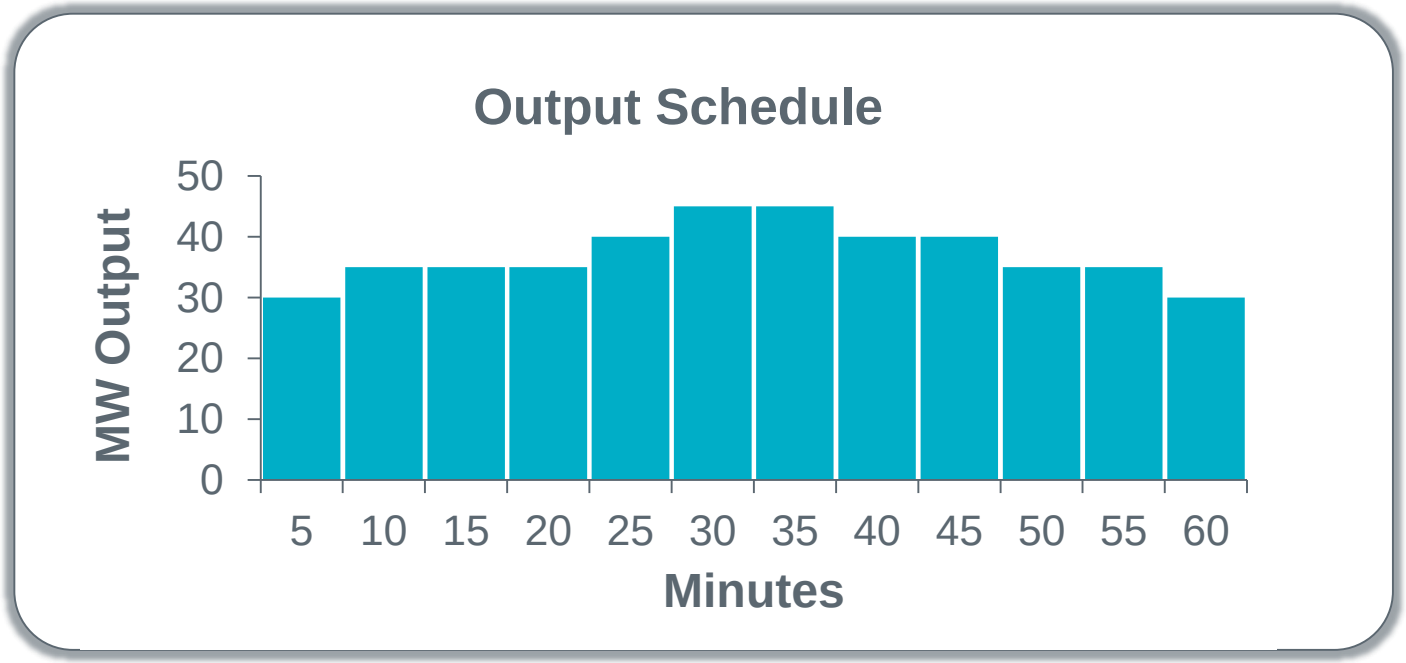
Submitted for:

- Resources currently online
- Quick Start Generation Resources (QSGRs)

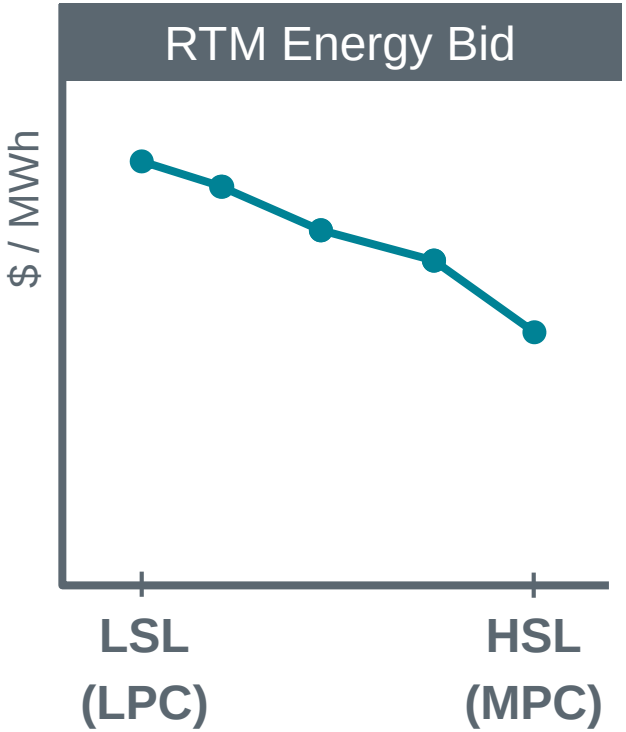
Expected to span LSL to HSL

Alternate "Offer" for a Generation Resource:

- Specifies desired output for each five-minute interval
- Price taker at specified output level



"Offer" for Load Resources dispatched by SCED:



May be submitted for:

- Qualified Controllable Load Resources
- Charging load for Energy Storage Resource

Expected to span LSL to HSL

The Mind of SCED

SCED Objective

- Dispatch Resources at minimum cost
- Subject to various constraints
  - Security constraints
    - Power Balance Constraint
    - Transmission Constraints
  - Resource Dispatch Limits

SCED

SCED Objective – Minimize Costs

Minimize:

Energy Costs + *Penalty Costs*

Penalty Costs include:

- Cost for violating Power Balance Constraint
- Cost for violating a Transmission Constraint

SCED

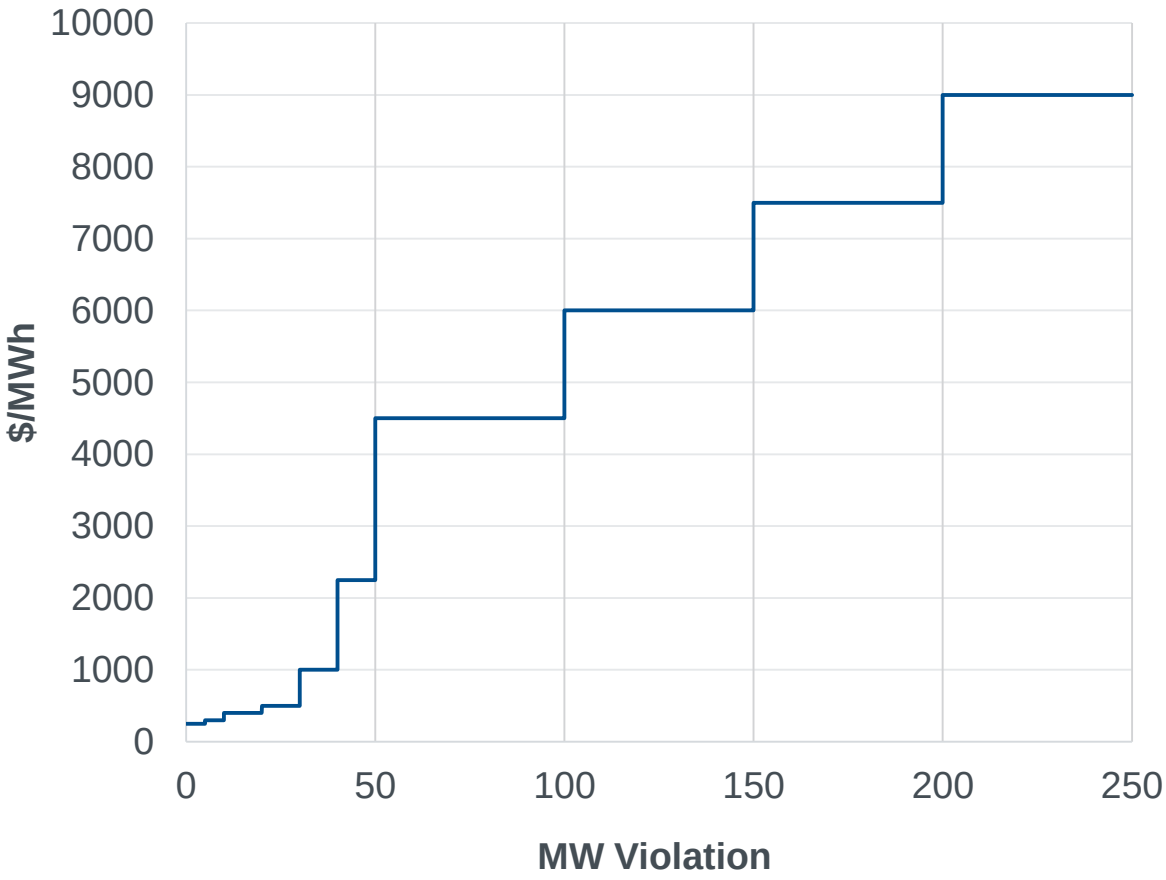
SCED optimization calculates Shadow Prices

- SP_{demand} for the power balance constraint
- SP_c for each transmission constraint

Penalty costs achieved through Shadow Price Caps

- Power Balance Penalty is maximum limit of SP_{demand}
- Each Transmission constraint has a max SP_c

Power Balance Penalty



Under-Generation

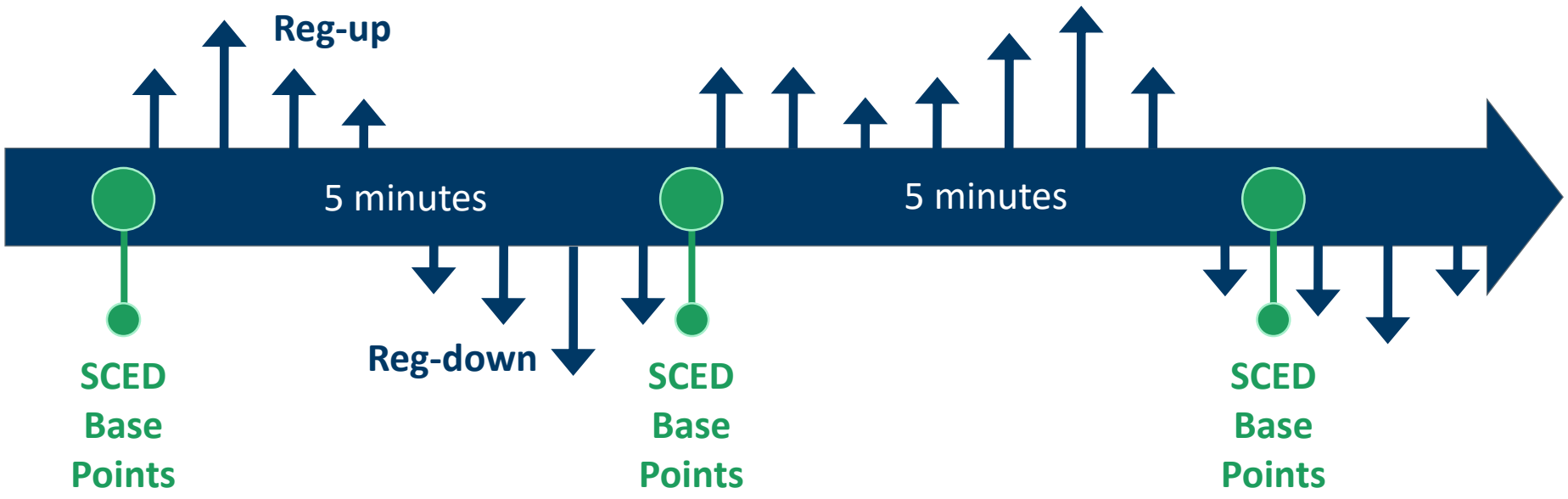
MW Violation	$/MWh
MW ≤ 5	250
5 < MW ≤ 10	300
10 < MW ≤ 20	400
20 < MW ≤ 30	500
30 < MW ≤ 40	1000
40 < MW ≤ 50	2250
50 < MW ≤ 100	4500
100 < MW ≤ 150	6000
150 < MW ≤ 200	7500
200 < MW	9001

Over-Generation

MW Violation	$/MWh
MW < 100,000	-250

Power Balance Violations

Any Power Balance violation by SCED will be covered by Regulation



Penalty for Violating Transmission Constraint

Shadow Price Caps

Type of Violation	Voltage	$/MWh
Base Case / Voltage	N/A	9251
N-1 Constraint	69kV	2800
	138kV	3500
	345kV	4500

Cost for violating constraint depends on

- Shadow Price Cap
- MW violation amount

Determining Locational Marginal Prices for Energy

$$LMP_{bus} = SP_{demand} - \sum_{c} SF_{bus,c} * SP_{c}$$

Shift Factor of the bus on Transmission Constraint "c"

Also known as System Lambda (λ)

. . . Any of these Shadow Prices may be set by a cap

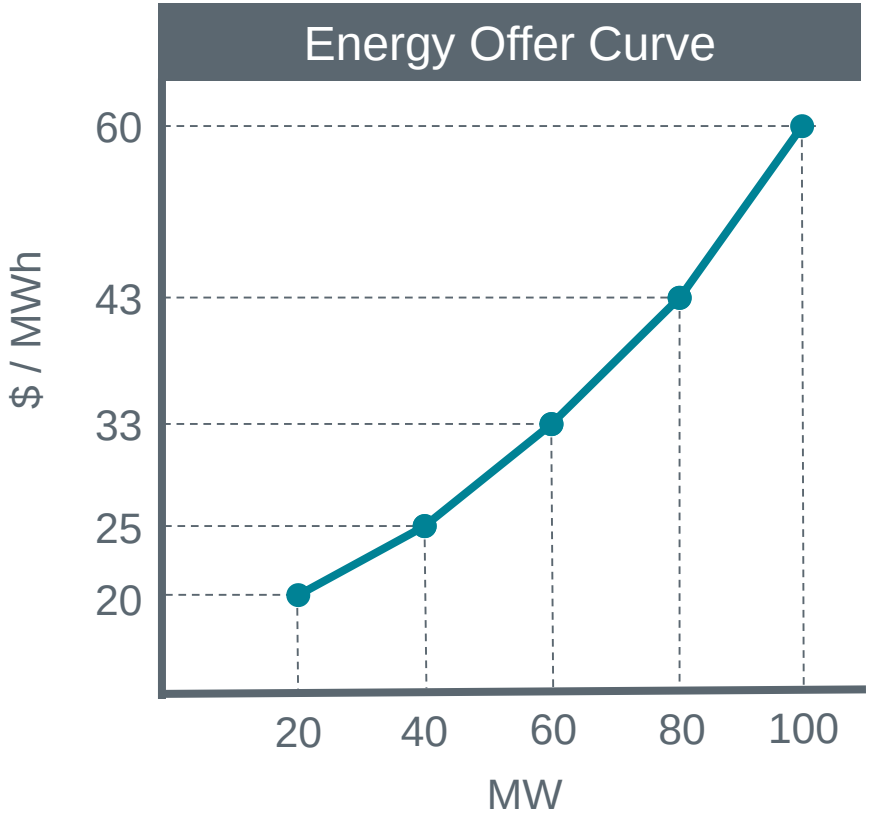
Scenario

A Generation Resource is available for SCED dispatch

SCED runs at 1100 and dispatches the Resource to 80MW @$43.

SCED runs at 1105 and dispatches Resource to 55MW @ -$1000

What is happening?



Load Frequency Control
&
Primary Frequency Response

Load Frequency Control

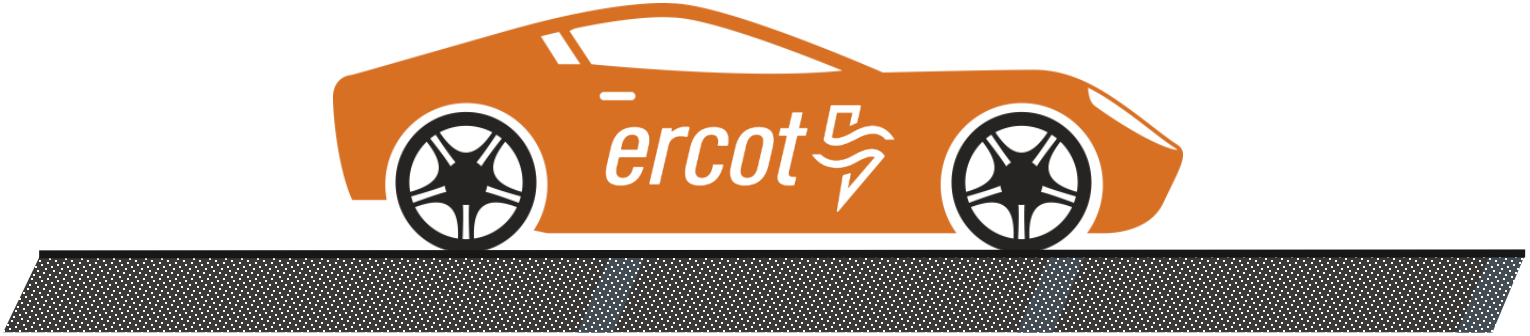
- Maintains system frequency, by
- Increasing/decreasing real power output of Resources,
- Without cost optimization

Primary Frequency Response

- Stabilizes system frequency, by
- Increasing/decreasing real power output system-wide
- Without cost optimization

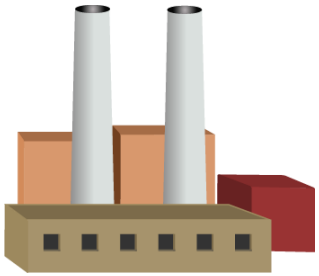
. . . so what are the differences?

Governor Control Systems



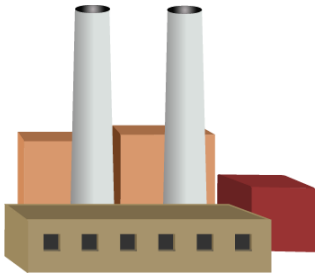
The following units must have Governor systems:

- Generation Resources
- Settlement Only Transmission Generators
- Settlement Only Transmission Self-Generators
- Controllable Load Resources

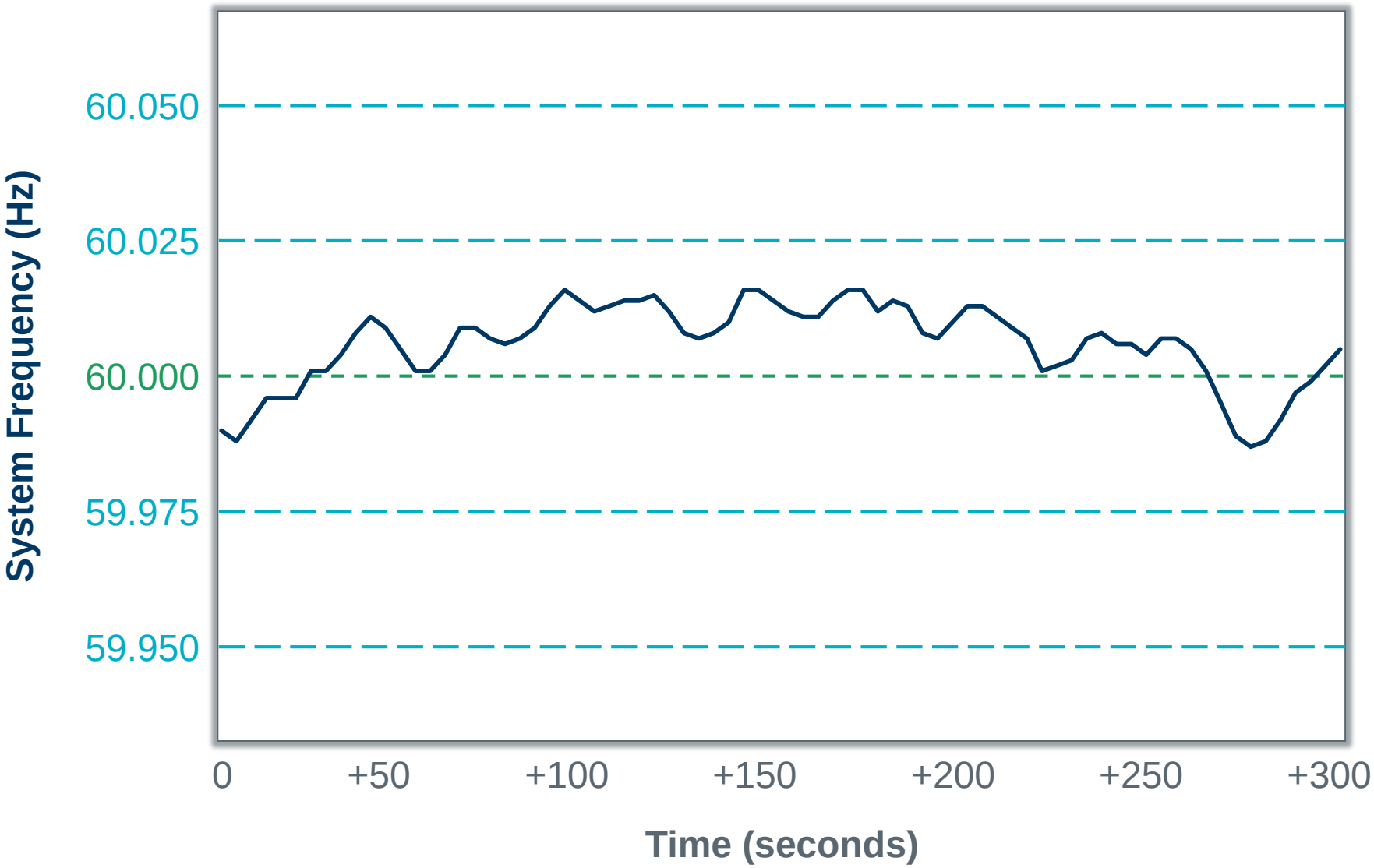


Governors must respond to changes in system frequency

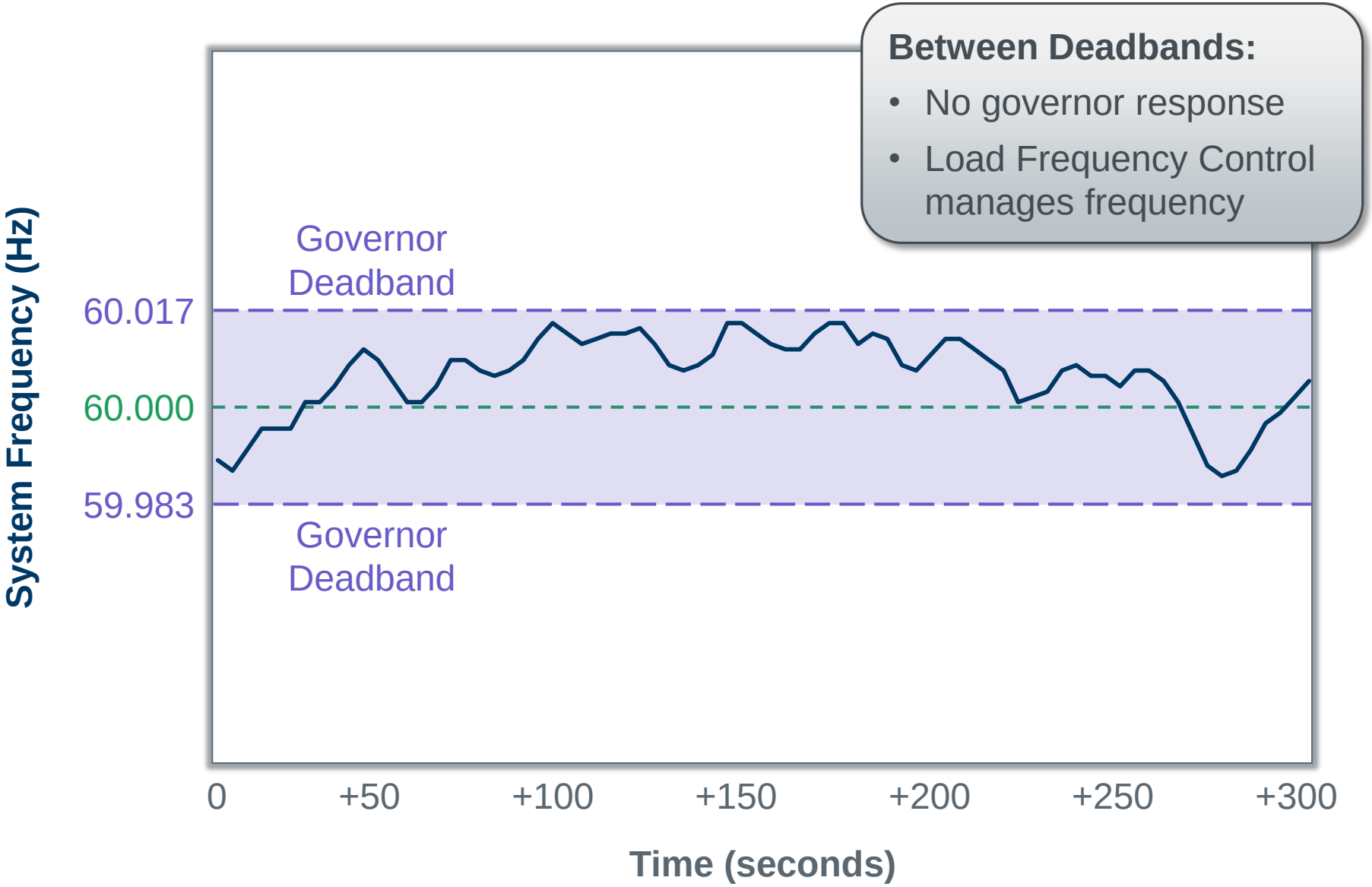
. . . after a point



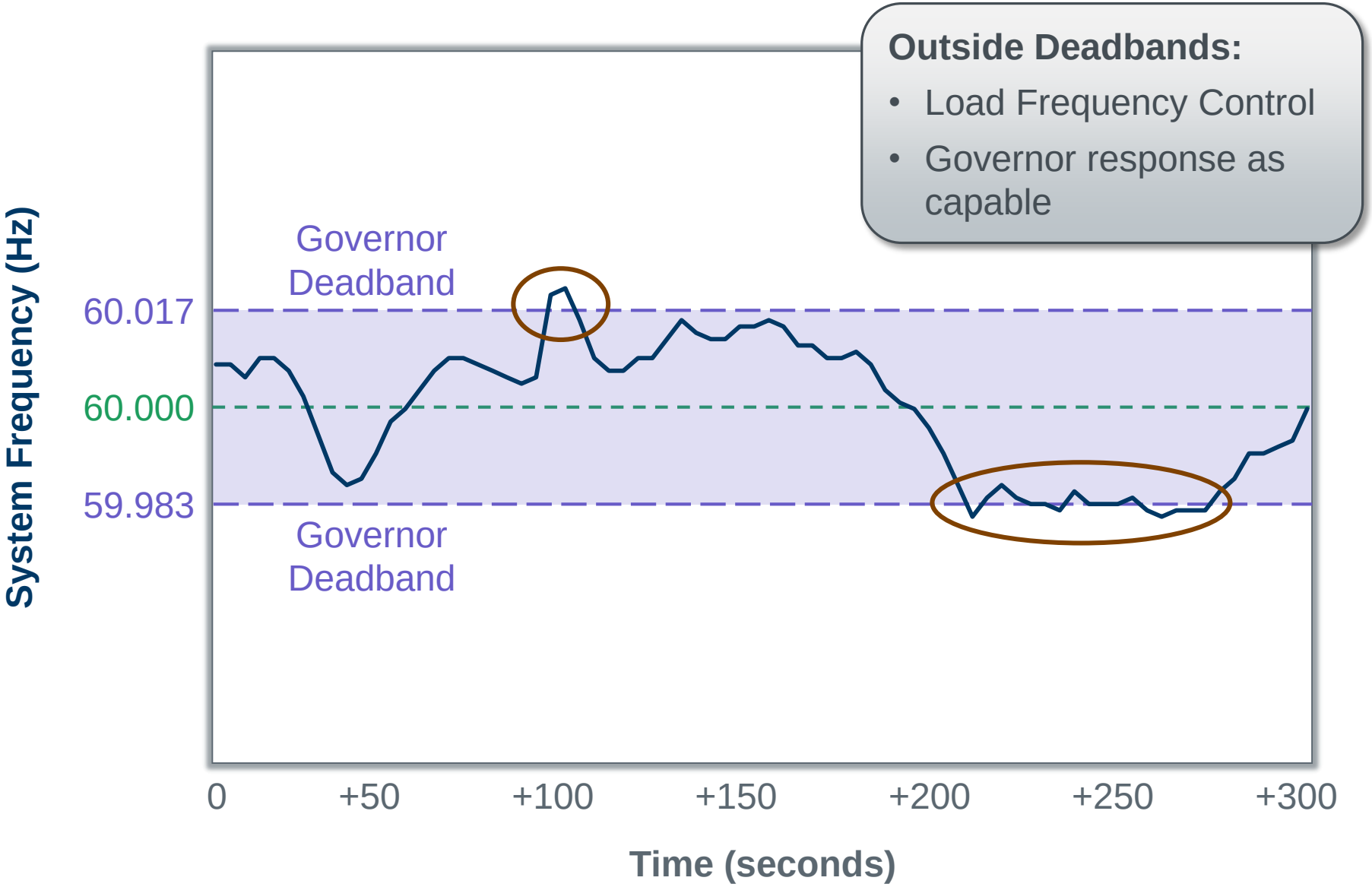
Control of System Frequency



System Frequency Control between Governor Deadbands



System Frequency Control outside Governor Deadbands



Governor Droop and Deadband Settings

Generator Type	Max. Droop
Combined Cycle Combustion Turbines	4%
All Other Generating Units, Generating Facilities and CLRs	5%

Generator Type	Max. Deadband
Steam or Hydro Turbines with Mechanical Governors	+/- 0.034 Hz
All Other Generating Units and Generating Facilities	+/- 0.017 Hz
Controllable Load Resources (CLRs)	+/- 0.036 Hz

Primary Frequency Response (PFR)

Each Resource must provide proportional response

- When frequency is high

$$PFR = \frac{\Delta freq - Generator\ Deadband}{Droop * 60 - Generator\ Deadband} * (-1) * HSL$$

- When frequency is low

$$PFR = \frac{Generator\ Deadband - \Delta freq}{Droop * 60 - Generator\ Deadband} * (-1) * HSL$$

For IRRs, HSL is current capability.

Example

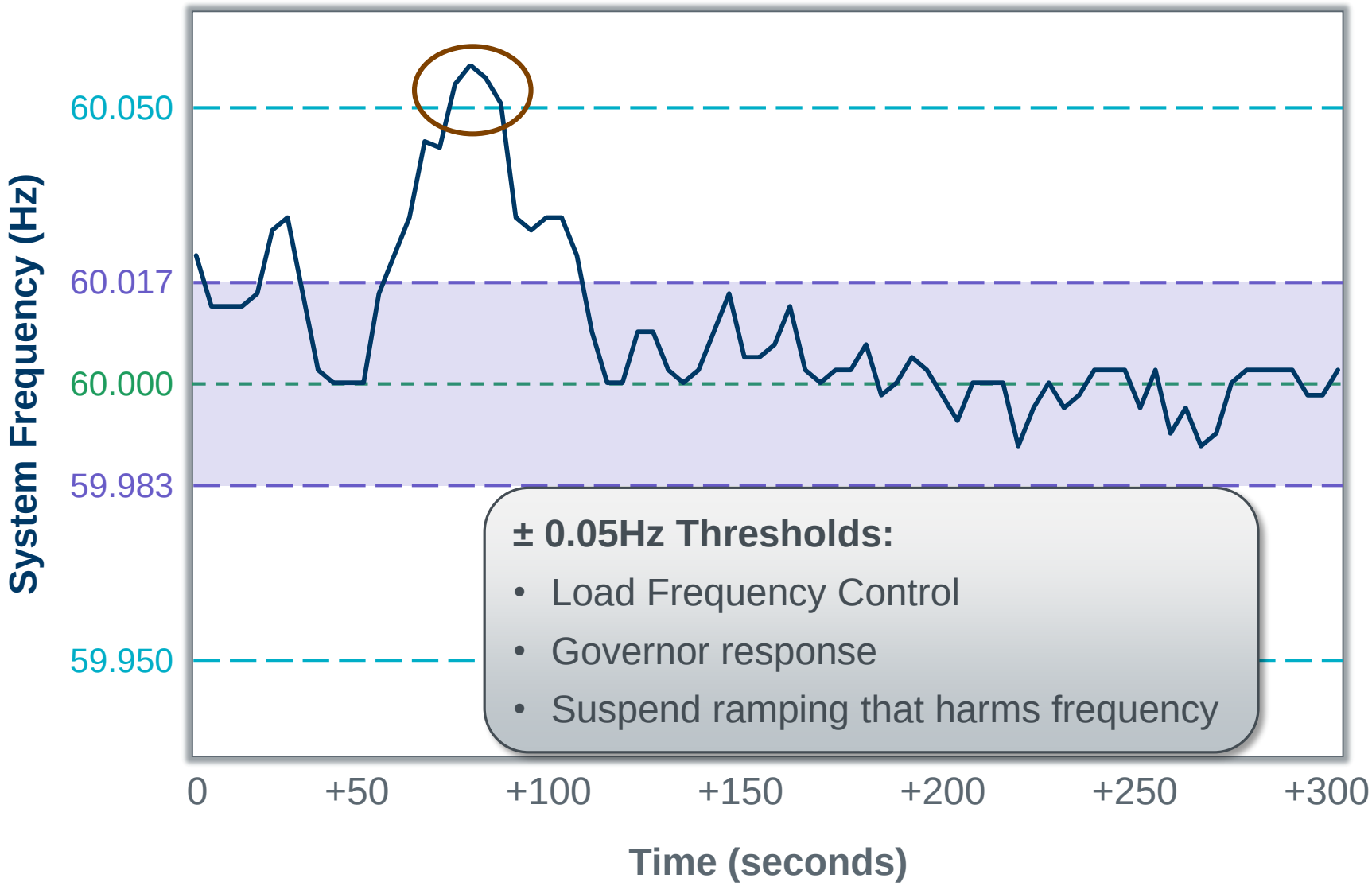
Primary Frequency Response

System Frequency reaches 60.02 Hz

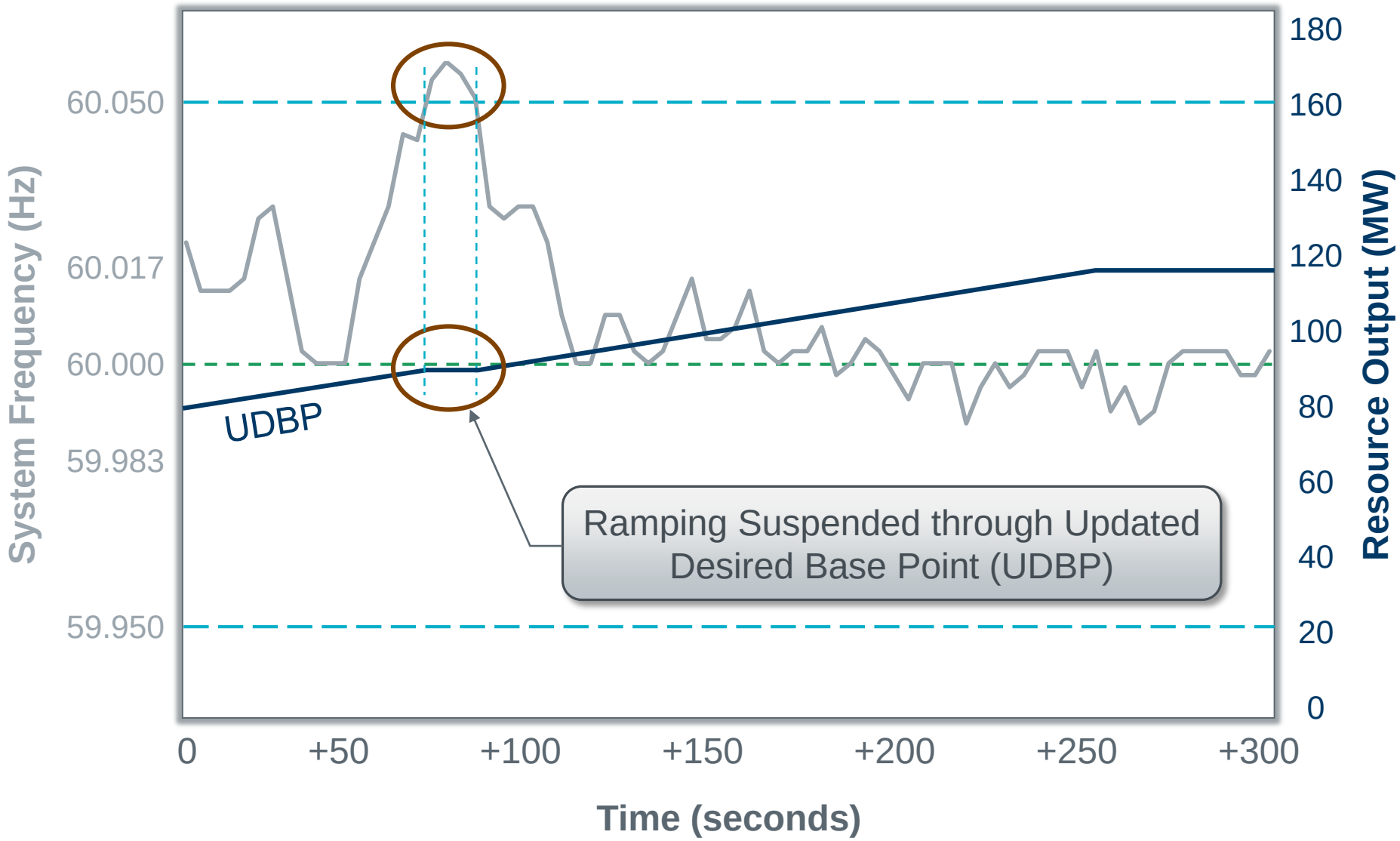
Wind Generation Resource Dusty Mesa has HSL of 100MW, based on current conditions.

What is Dusty Mesa's expected Primary Frequency Response?

System Frequency Control – Ramping Suspension



Ramping Suspension – Updated Desired Base Point



Updated Desired Base Point

- 4 second ICCP signal
- Expected MW output of a ramping Resource
  - Calculated to reach Base Point in 240 seconds
  - Does not include Regulation Deployments

Provision and Deployment of Ancillary Services

Topics in this Section Include

1. Operational Requirements for Ancillary Services
2. Resource Limits by Ancillary Service Product
3. Ancillary Service Deployment Methodologies

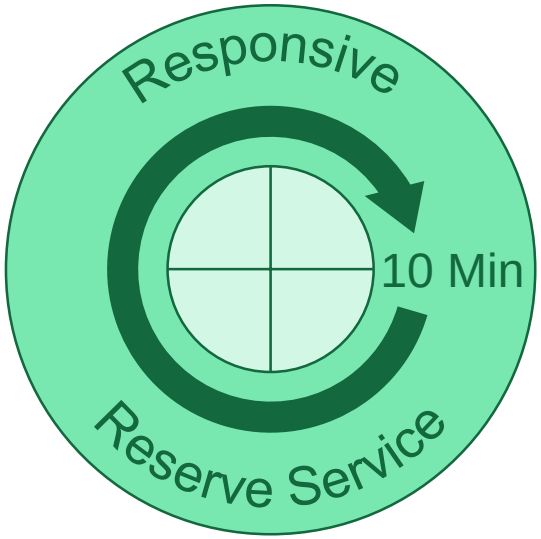
Provides capacity used to maintain system frequency

Regulation Service Products	General Requirements
Regulation Up	Respond within 5 sec
Regulation Down	
Fast Responding Regulation Up	Responds within 60 cycles of ERCOT signal -or- By frequency trigger (+/- 0.09Hz)
Fast Responding Regulation Down	

Must be capable of ramping through reserved capacity in 5 minutes

Provides capacity reserves to:

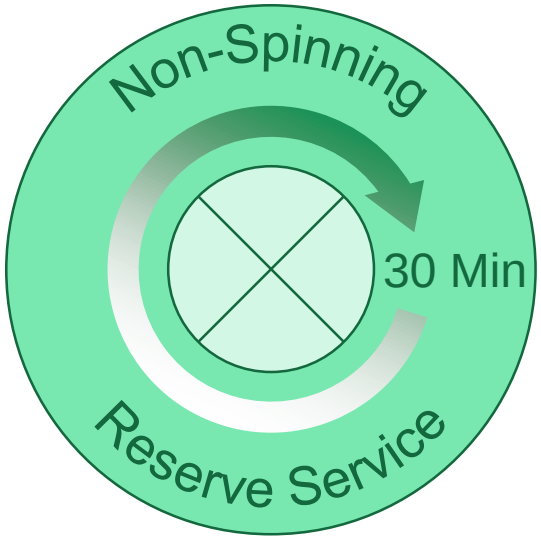
- Respond to significant frequency deviations
- Serve as backup Regulation Up
- Provide additional capacity during an Energy Emergency Alert (EEA)



Must be capable of ramping through reserved capacity in 10 minutes

Provides additional reserves with longer lead time

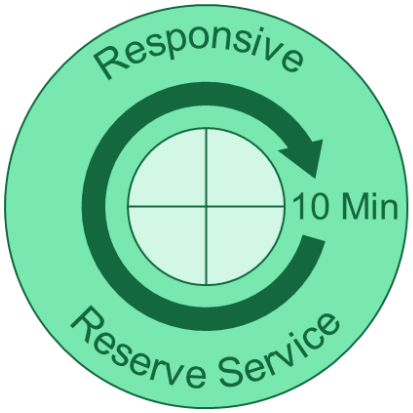
- Must be capable of running at a specified output level for at least one hour
- May be used for system-wide or local needs



Must be capable of ramping through reserved capacity in 30 minutes

Who carries what?

On-line Generation Resource
Controllable Load Resource
Energy Storage Resource



On-line Generation Resource
Controllable Load Resource
Load Resource on Under-Frequency Relay
Energy Storage Resource

Off-line Generation Resource
On-line Generation Resource
Controllable Load Resource

Topics in this Section Include

1. Operational Requirements for Ancillary Services
2. Resource Limits by Ancillary Service Product
3. Ancillary Service Deployment Methodologies

The following Resource limits are enforced in Real-Time:

Resource Type	Resource Limit
On-line Generation Resources	Responsive Reserve ≤ 20% HSL and ≤ 10 * Emergency Ramp Rate
Off-Line Generation Resources	Non-Spin Reserve ≤ HSL
Hydro Resource as Synchronous Condenser	Responsive Reserve ≤ 20 second capability
All On-line Resources	LSL + Responsive + Regulation + Non-Spin ≤ HSL

The following system limits are enforced in Real-Time:

Ancillary Service	System Limit
Fast Responding Regulation Up	System total may not exceed 65 MW
Fast Responding Regulation Down	System total may not exceed 35 MW
Responsive Reserve	Load Resources on UFR may not exceed • 60% of ERCOT Responsive Reserve requirement • 60% of QSE's Self arranged Responsive Reserve Obligation

Topics in this Section Include

1. Resource Limits by Ancillary Service Product
2. Ancillary Service Deployment Methodologies

Load Frequency Control (LFC)

- Responds to frequency deviations
- Deploys certain Ancillary Services
  - Regulation Up
  - Regulation Down
  - Responsive Reserve
- Provides Updated Desired Base Point

Provides capacity that can respond to signals from ERCOT in order to maintain system frequency

- Deployed proportionally by QSE's share of Regulation provided
- QSE choses how to distribute across their Resources

But how does LFC know how much Regulation to Deploy?

ERCOT Area Control Error (ACE) is the MW-equivalent correction needed to control the actual system frequency to the scheduled system frequency value.

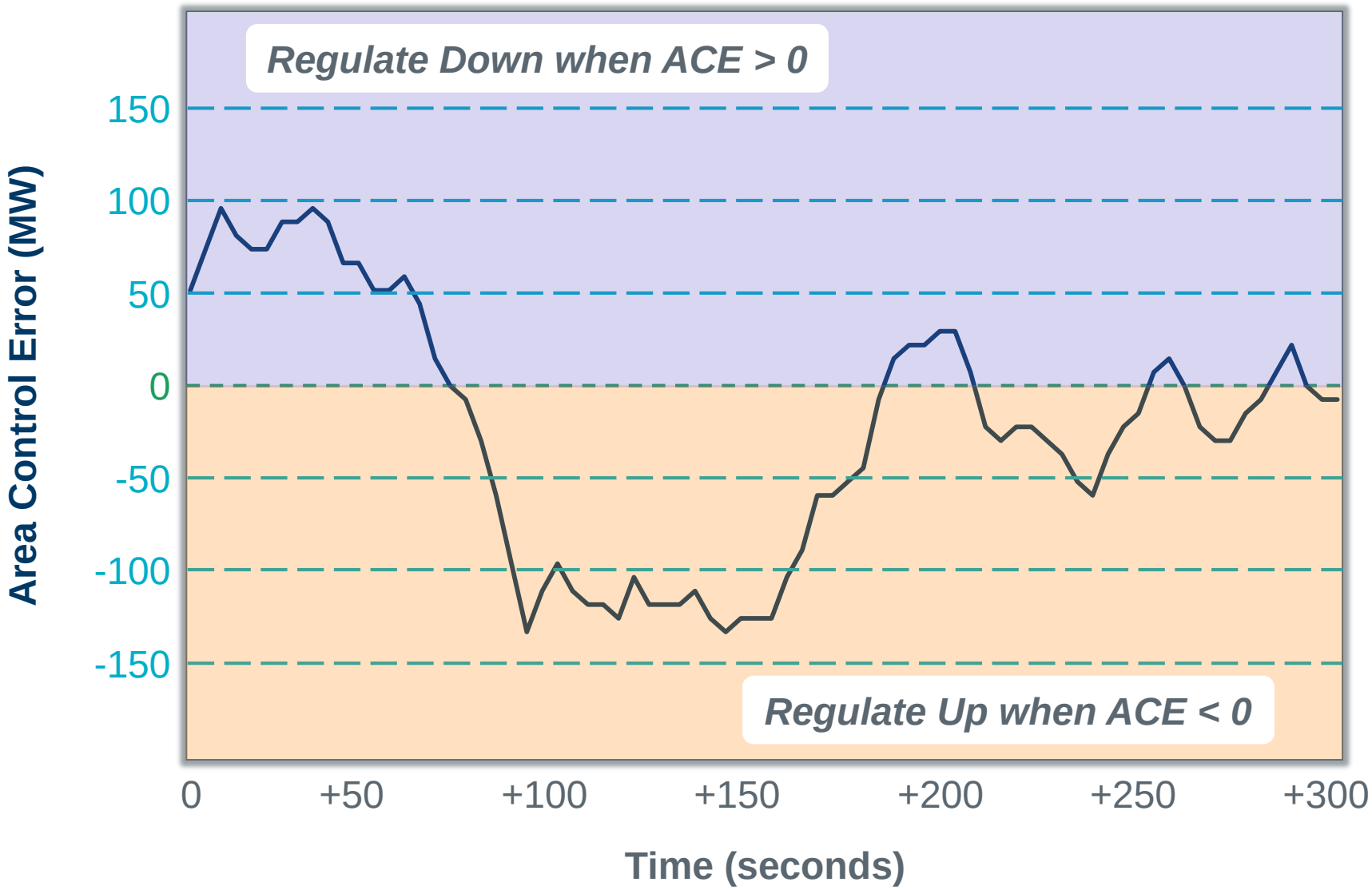
The Equation

ERCOT ACE = -10ß (F_S – F_A)

Adjusted for difference between Resources' UDBP and actual MW output

Legend	
F_S	Scheduled Frequency
F_A	Actual Frequency
ß	System Frequency Bias (Currently 895 MW/0.1Hz)

Area Control Error



Regulation Service Communications

QSEs to ERCOT:

- AS Resource Responsibility
- Participation Factors
- Raise/Lower Block Status

ERCOT to QSEs:

- Regulation MW
- Fast Responding Regulation MW

Participation Factors

- Separate values for Regulation-Up and Regulation-Down
- Used to calculate what remains on each Resource
- Used in Base Point Deviation Settlement

Raise Block Status and Lower Block Status

- Indicate that Resource is temporarily unable to respond
- Set only until Resource limits and/or Ancillary Service telemetry can be updated
- Reduces QSE's overall Regulation deployment

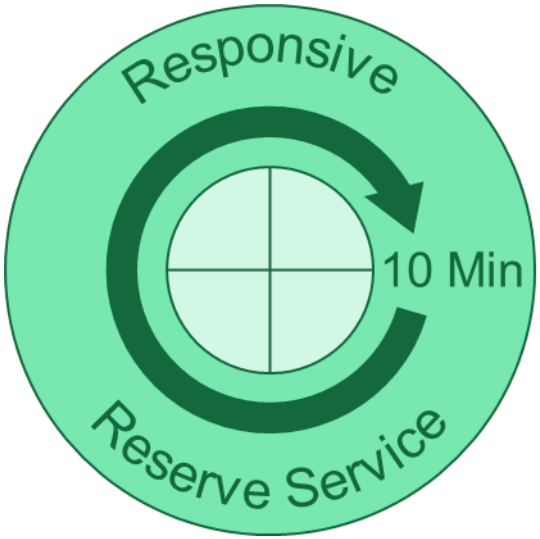
Two modes of Deployment

- By ERCOT Regulation Control Signal
  - ERCOT determines MW deployment
  - Resource must deploy to specified level in 60 cycles
- By Frequency Trigger
  - Resource auto deploys at +/- 0.09 Hz
  - Resource must deploy 100% within 60 cycles of trigger

In either case, ERCOT will recall when system frequency recovers

Responsive Reserve Service

Used under normal operations to recover from significant frequency deviations

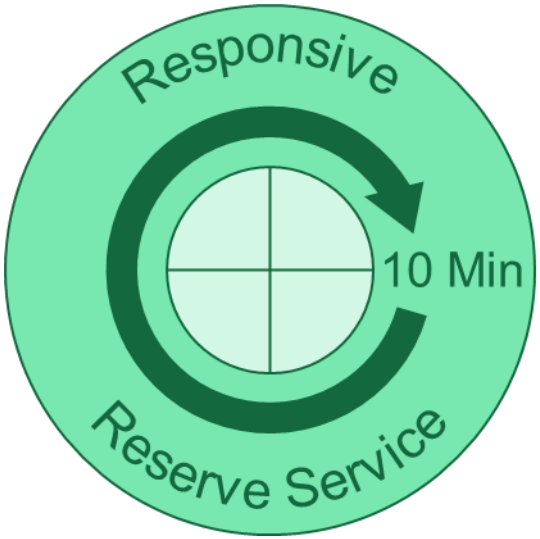


Multiple modes of deployment

- Manual
  - ICCP Control Signal
  - XML Message (Load Resources)
- Frequency Triggers

Responsive Reserve Service

Used under normal operations to recover from significant frequency deviations



Frequency Triggers

- 59.85 – Fast Frequency Response (FFR) within 15 cycles
- 59.7 Hz – Load Resources on Under Frequency Relay trip within 30 cycles

Responsive Reserve Communications

QSEs to ERCOT:

- AS Resource Responsibility
- AS Schedule

ERCOT to QSEs:

- Responsive Reserve MW
- Resource Base Point MW

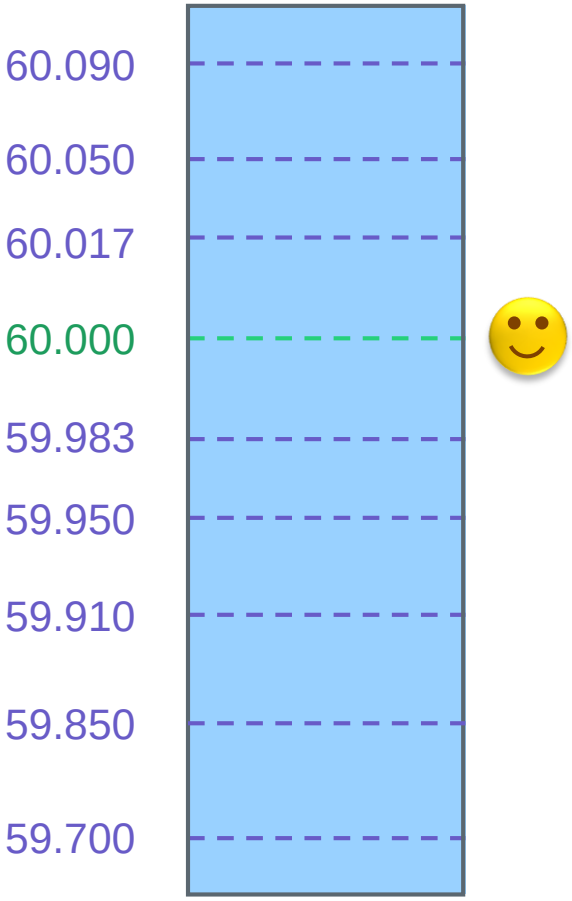
Responsive Reserve Deployment

QSE reduces AS Schedules Within 1 minute

ERCOT triggers SCED to dispatch Resources

Class Activity

Name that Frequency!



Non-Spinning Reserve Service

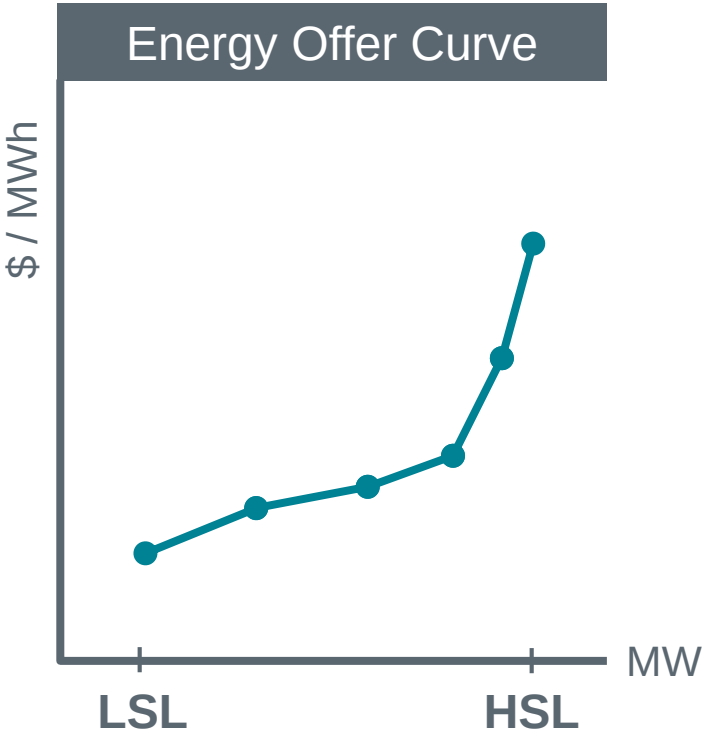
Provides additional capacity reserves that can be utilized within 30 minutes

Uses

- System-Wide capacity shortage
- Local capacity shortage
- Recover Responsive Reserve Service in a timely manner

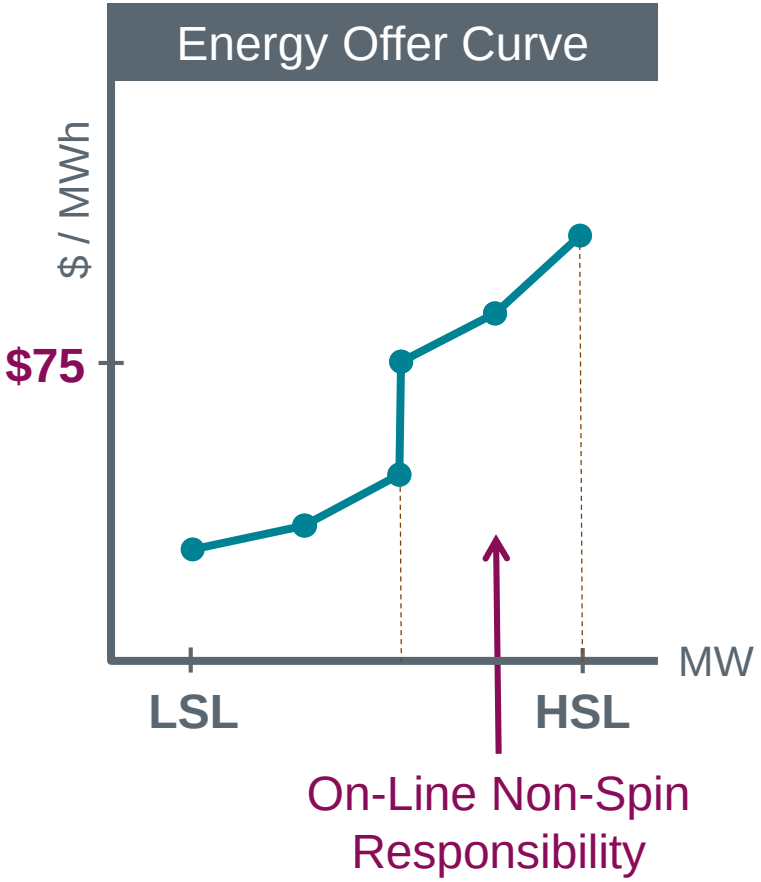
Off-Line Generation Resource

- Deployed by Operator Dispatch Instruction
  - Always 100% of individual Resource Responsibility
  - Deployed in economic order
- QSE responsibilities
  - Non-Spin Schedule set to zero within 20 minutes
  - Resource dispatchable by SCED within 25 minutes



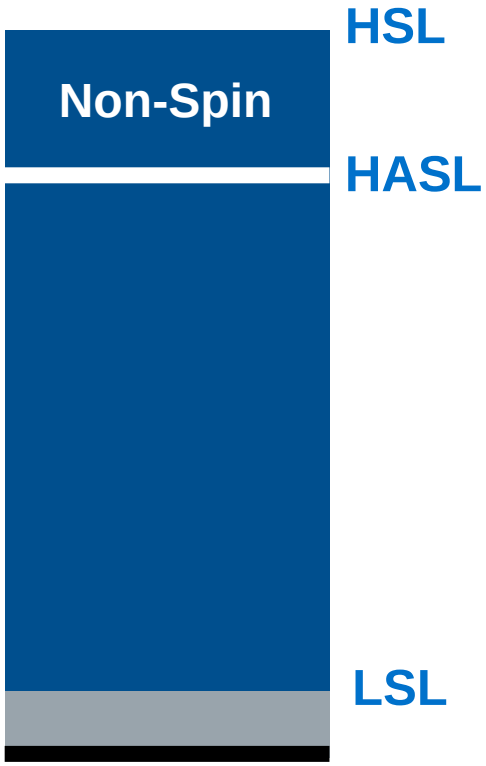
On-Line Generation Resource

- Standing Deployment During Operating Hour
  - Non-Spin Schedule = 0
  - Non-Spin Responsibility priced at or above $75
- SCED dispatches Non-Spin capacity as economics dictate



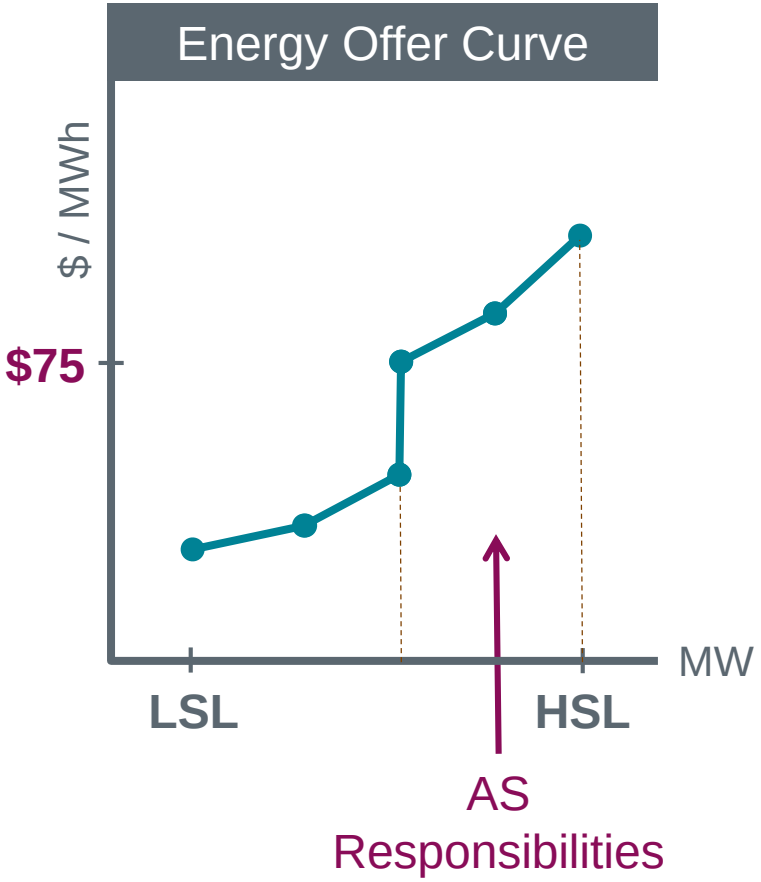
Non-Frequency Responsive Capacity (NFRC) from power augmentation

- Deployed by Operator Dispatch Instruction
- QSE responsibilities
  - Non-Spin Schedule = Power Augmentation MW
  - Non-Spin Schedule = 0 within 20 minutes of deployment



On-Line Non-Spin with other Ancillary Services

- The following products must also be priced at or above $75
  - Regulation Up
  - Responsive Reserve
  - NFRC



Real-Time Settlements

Topics in this Section Include

1. Real-Time Energy Imbalance
2. Settlement of RUC-Committed Resources

Real-Time Energy Imbalance at a Resource Node:

$$(-1)\left(\left(\begin{array}{c}\text{DAM Energy Purchases}\\+\\\text{Trade Energy Purchases}\end{array}\right)-\left(\begin{array}{c}\text{DAM Energy Sales}\\+\\\text{Trade Energy Sales}\end{array}\right)\right)*\text{RTSPP}$$

$$+\ (-1)\left(\text{Metered Generation}\right)*\text{RTRMPR}$$

At a Resource Node,

RTSPP is used to settle financial transactions

RTSPP = **RTRSVPOR** + **RTRDP** + Time-Weighted Average (LMPs)

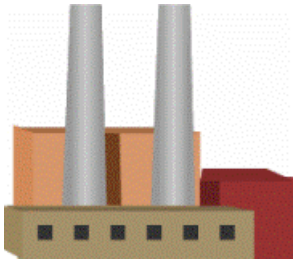
RTSPP	Real-Time Settlement Point Price
RTRSVPOR	Real-Time Reserve Price for On-Line Reserves
RTRDP	Real-Time On-Line Reliability Deployment Price

At a Resource Node,

RTRMPR is used to settle physical energy production

RTRMPR = RTRSVPOR + RTRDP + (Base-Point * Time) Weighted Average [LMPs]

RTRMPR	Real-Time Resource Meter Price
RTRSVPOR	Real-Time Reserve Price for On-Line Reserves
RTRDP	Real-Time On-Line Reliability Deployment Price

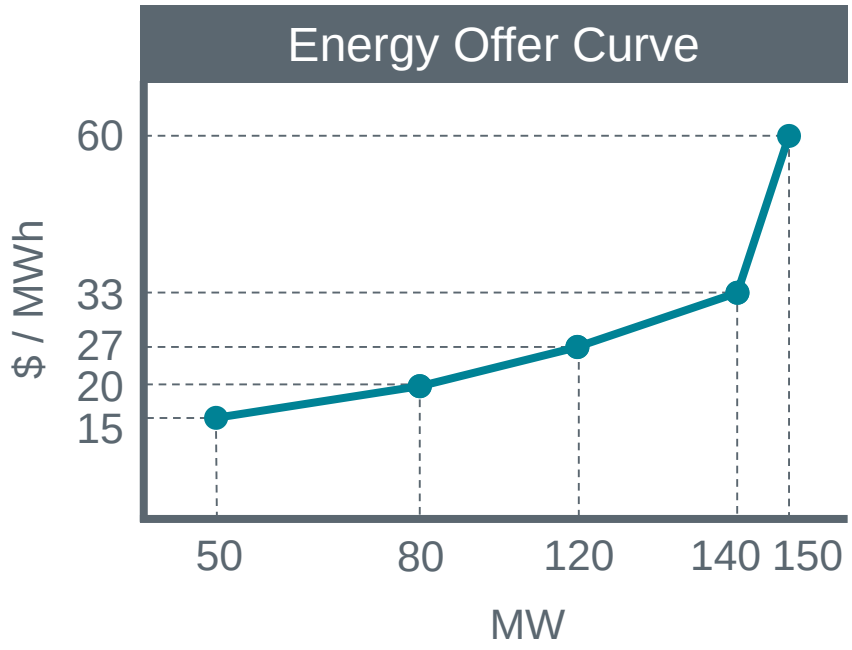


Scenario 1

Generation Resource BIGGEN1 was awarded in DAM and runs in Real-Time

- Awarded 80MW each hour for Hours 1 - 4
- On-line and dispatched in Real-Time during Hours 1 - 4

Hour 1	RTRMPR	RTSPP	MWh
0015	19	18	18
0030	20	20	20
0045	22	21	22
0100	23	22	24
		Total	84



Scenario 1

Real-Time Energy Imbalance for Interval 0015:

$$(-1)\left(\left(\begin{array}{c}\text{DAM Energy Purchases}\\+\\\text{Trade Energy Purchases}\end{array}\right)-\left(\begin{array}{c}\text{DAM Energy Sales}\\+\\\text{Trade Energy Sales}\end{array}\right)\right)*\text{RTSPP}$$

$$+\ (-1)\left(\text{Metered Generation}\right)*\text{RTRMPR}$$

Which simplifies and re-arranges to . . .

$$(-1)*\left(\begin{array}{c}\text{Metered}\\\text{Generation}\end{array}*\text{RTRMPR}-\left(\begin{array}{c}\text{DAM Energy Sales}\\+\\\text{Trade Energy Sales}\end{array}\right)*\text{RTSPP}\right)$$

Scenario 1

Real-Time Energy Imbalance for Interval 0015:

$$(-1) * \left[\text{Metered Generation} * \text{RTRMPR} - \left(\boxed{\text{DAM Energy Sales}} + \text{Trade Energy Sales} \right) * \text{RTSPP} \right]$$

$$(-1) * \left[18\ \text{MWh} * \$19/\text{MWh} - 20\ \text{MWh} * \$18/\text{MWh} \right] = \$18$$

Scenario 1

Real-Time Energy Imbalance for Interval 0045:

$$(-1) * \left[\text{Metered Generation} * \text{RTRMPR} - \left(\boxed{\text{DAM Energy Sales}} + \text{Trade Energy Sales} \right) * \text{RTSPP} \right]$$

$$(-1) * \left[22\ \text{MWh} * \$22/\text{MWh} - 20\ \text{MWh} * \$21/\text{MWh} \right] = -\$64$$

Scenario 1

Real-Time Revenues across all hours

- On-line and dispatched in Real-Time during Hours 1 - 4
- Assume Responsive Reserve was never deployed

Is that all the revenue for BIGGEN1?

	Real-Time Revenue
Hour 1	$158
Hour 2	$200
Hour 3	$225
Hour 4	$250
Total	$833

Scenario 1

BIGGEN1 was also awarded Energy and Responsive Reserve in DAM

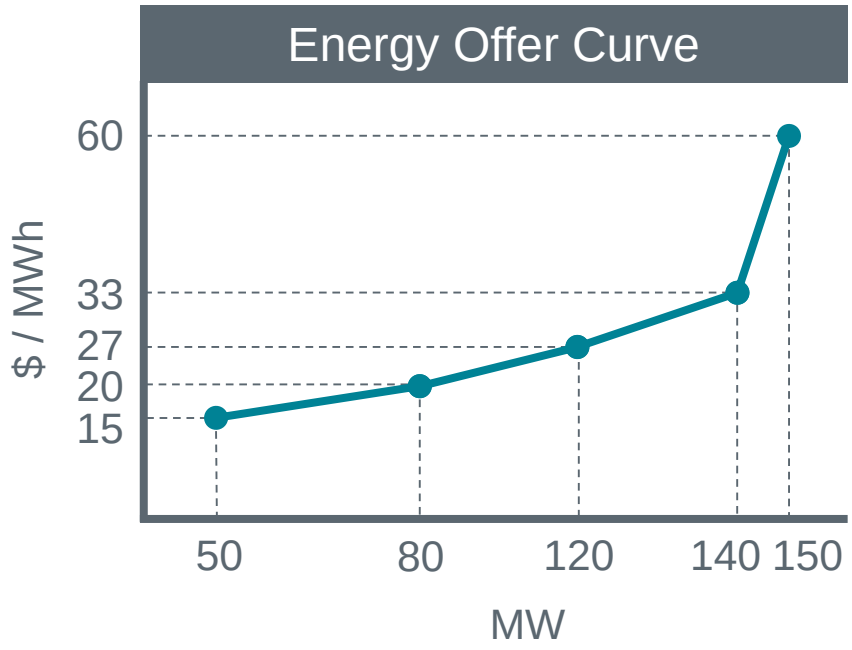
- Energy Award: 80MW @ $20 for Hours 1 - 4
- Responsive Reserve Award: 10MW @ $10 for Hours 1 - 4
- Make-Whole payment of $1075 per hour

	Real-Time Revenue	DAM Revenue	Total
Hour 1	$158	$2775	$2993
Hour 2	$200	$2775	$2975
Hour 3	$225	$2775	$3000
Hour 4	$250	$2775	$3025
Total	$833	$11,100	$11,993

Scenario 2

QSE schedules trades on BIGGEN1 and runs in Real-Time

- Startup Cost: $3000
- Minimum Energy Cost: $30/MWh
- LSL = 50 MW

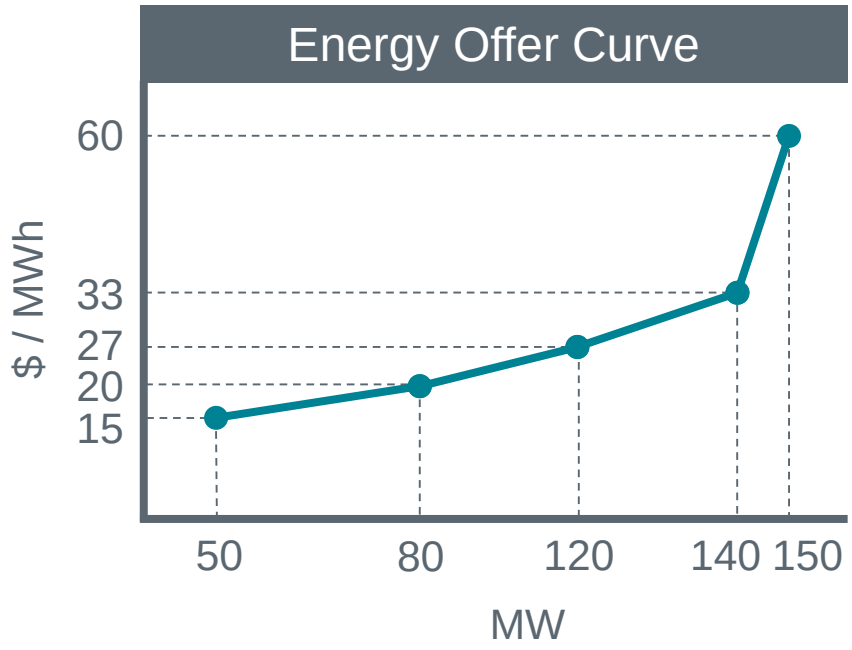


Scenario 2

QSE schedules trades on BIGGEN1 and runs in Real-Time

- 100MW in trades at the BIGGEN Resource Node for Hours 15 - 18
- QSE Starts Resource for Hour 15 and runs through Hour 18

Hour 15	RTRMPR	RTSPP	MWh
1415	27	27	30
1430	29	28	31
1445	31	30	33
1500	34	33	35
		Total	129



Scenario 2

Real-Time Energy Imbalance for Interval 1415:

$$(-1) * \left(\text{Metered Generation} * \text{RTRMPR} - \left(\text{DAM Energy Sales} + \boxed{\text{Trade Energy Sales}} \right) * \text{RTSPP} \right)$$

$$(-1) * \left(30\ \text{MWh} * \$27/\text{MWh} - 25\ \text{MWh} * \$27/\text{MWh} \right) = -\$135$$

Scenario 2

QSE schedules trades on BIGGEN1 and runs in Real-Time

- 100MW in trades at the BIGGEN Resource Node for Hours 15 - 18
- QSE Starts Resource for Hour 15 and runs through Hour 18

Is this Real-Time Revenue sufficient for BIGGEN1?

	Real-Time Revenue
Hour 14	$300
Hour 15	$972
Hour 16	$1122
Hour 17	$1275
Hour 18	$802
Hour 19	$406
Total	$ 4877

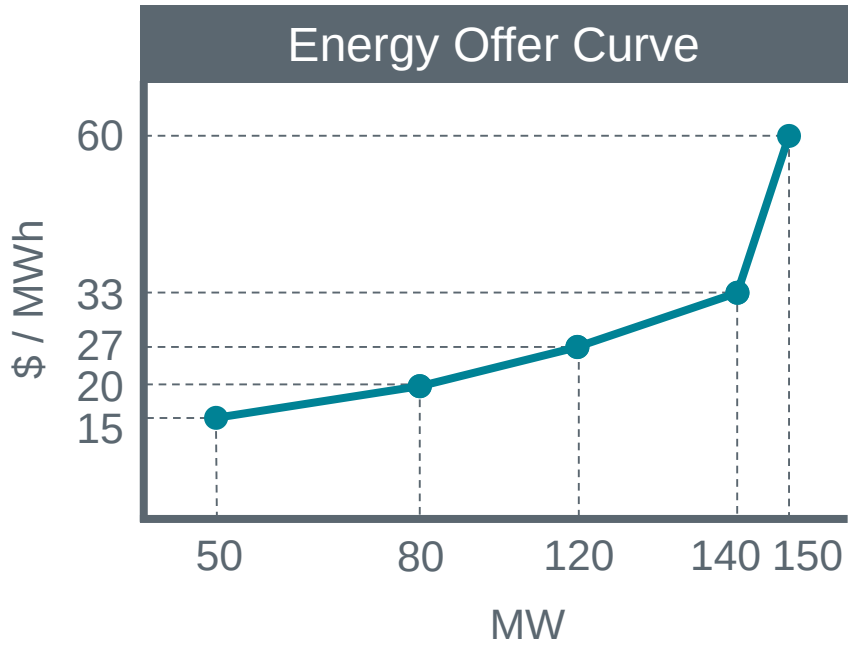
Topics in this Section Include

1. Real-Time Energy Imbalance
2. Settlement of RUC-Committed Resources

Scenario 3

Generation Resource BIGGEN1 is committed by RUC

- Startup Offer: $3000
- Minimum-Energy Offer: $30/MWh
- LSL = 50 MW

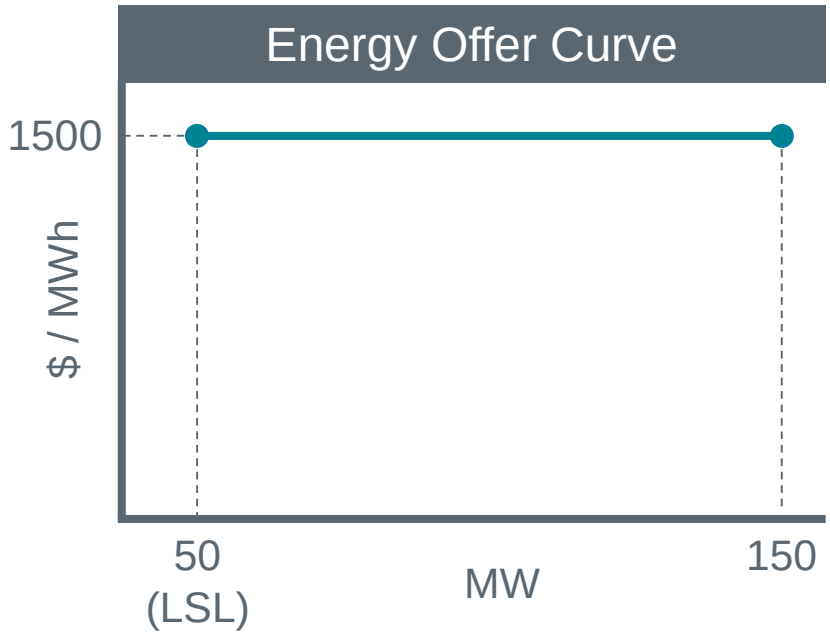


Scenario 3

Generation Resource BIGGEN1 is committed by RUC

- Committed for Hours 7 - 10
- QSE Starts Resource and ramps to LSL by 0600

Hour 7	RTRMPR	RTSPP	MWh
0615	20	20	12.5
0630	20	20	12.5
0645	20	20	12.5
0700	20	20	12.5
		Total	50



Scenario 3

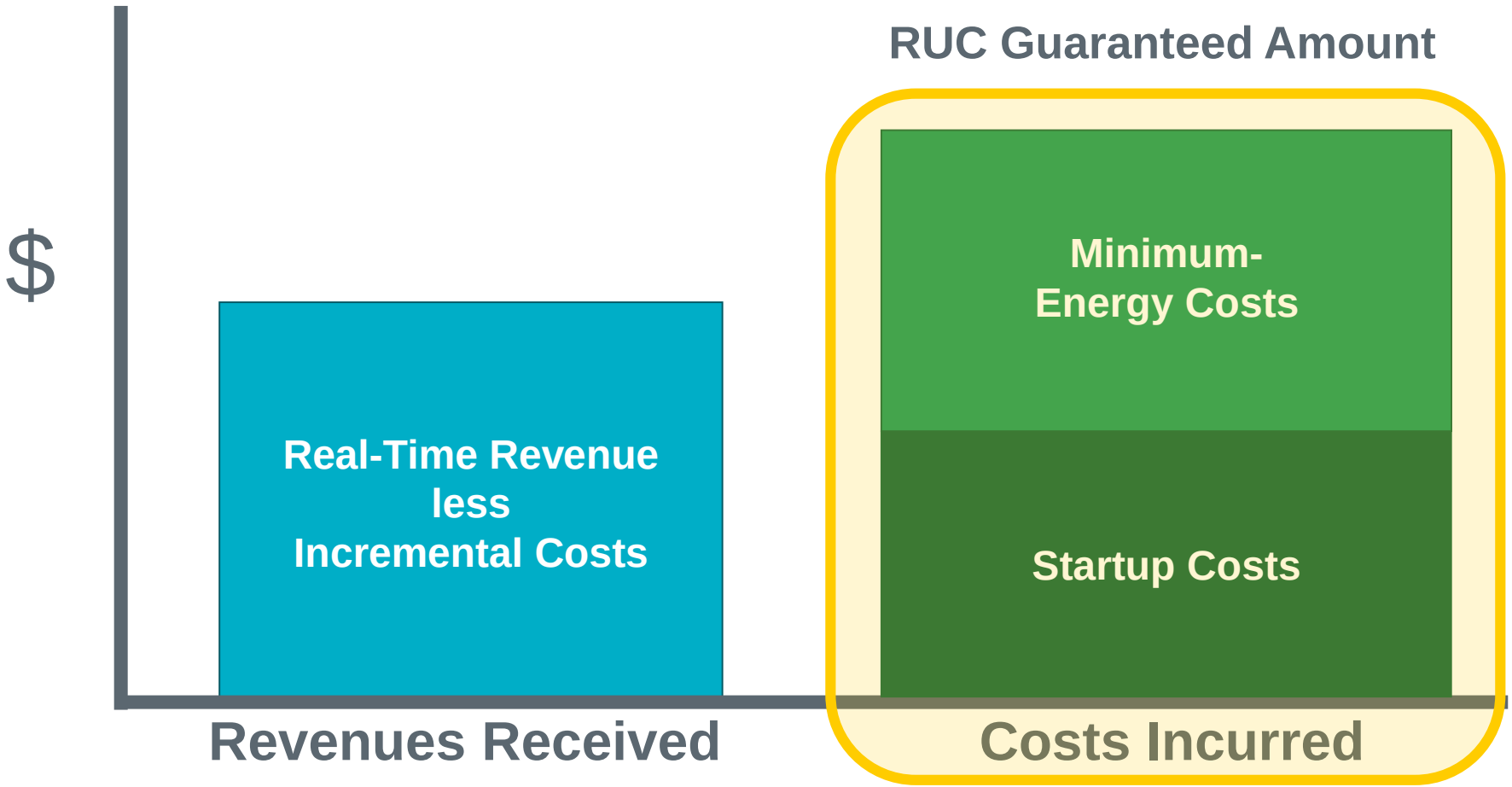
Real-Time Energy Imbalance for Interval 0615:

$$(-1) * \left(\text{Metered Generation} * \text{RTRMPR} - \left(\text{DAM Energy Sales} + \text{Trade Energy Sales} \right) * \text{RTSPP} \right)$$

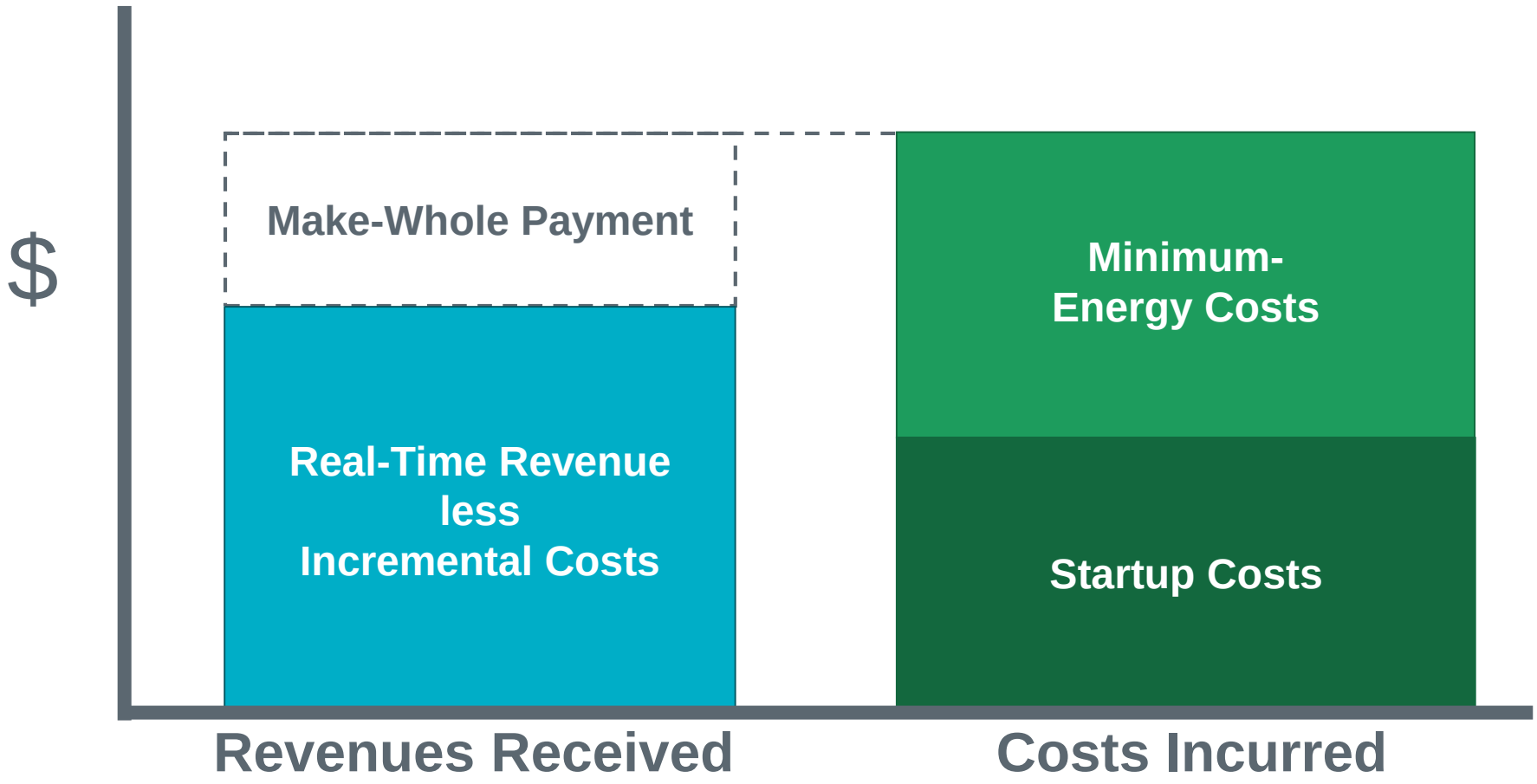
$$(-1) * \left(12.5\ \text{MWh} * \$20/\text{MWh} - 0 * \$20/\text{MWh} \right) = -\$250$$

At this rate, will they recover their Startup and Minimum-Energy Costs?

What if revenues are less than costs?

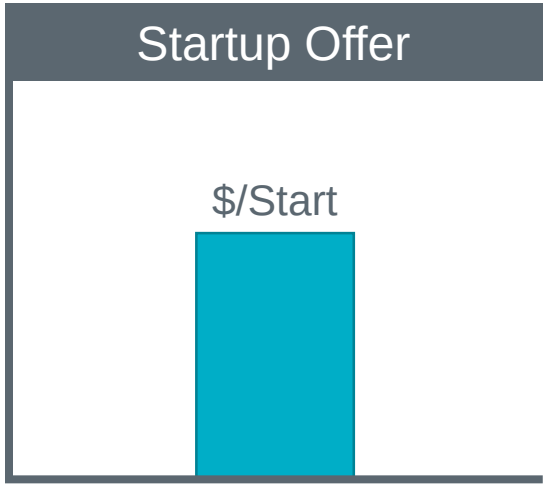


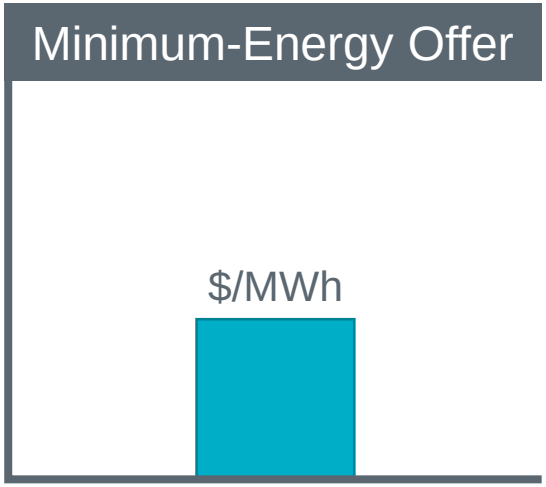
What if revenues are less than costs?



Costs to be made whole:

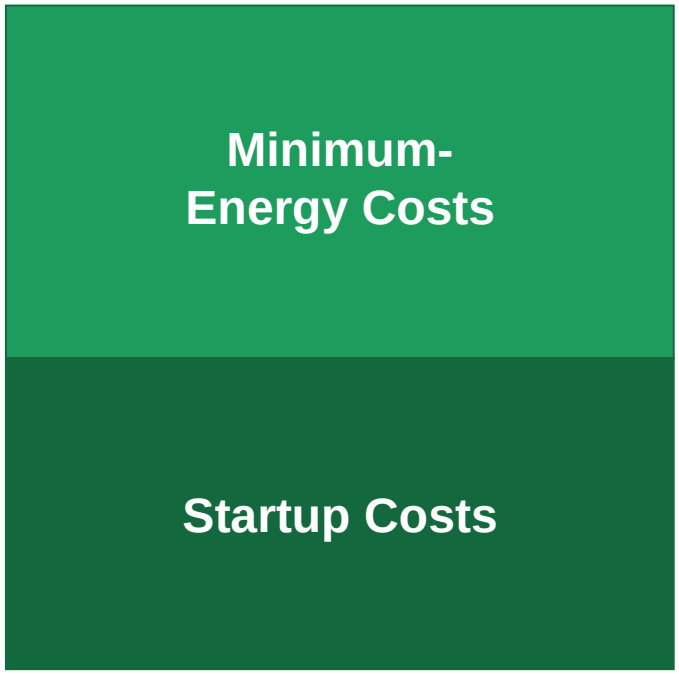
- Look to Three-Part Supply Offer for cost data
- Capped at Verifiable Costs if available
- Otherwise, capped at Generic Costs





Which costs are eligible?

- Must actually incur the costs
- Minimum-Energy Costs included for RUC hours the Resource actually runs
- Startup costs included for starts incurred due to the RUC instruction

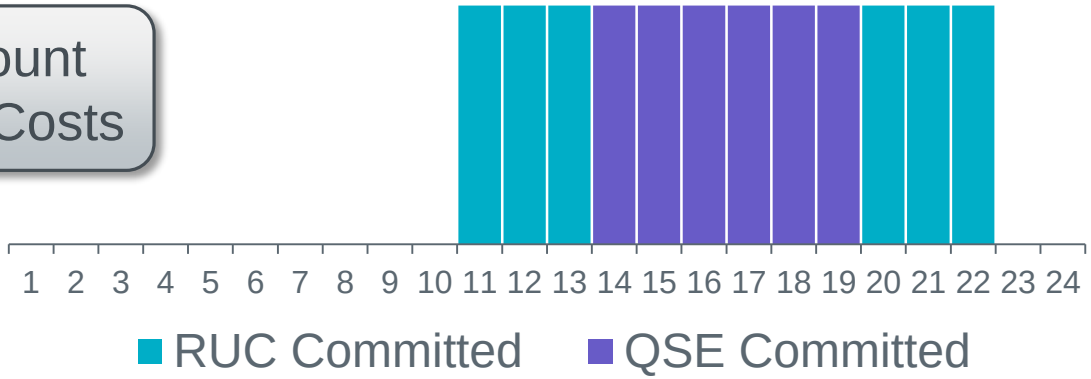


Costs Incurred

Startup Cost Eligibility

- One Start per contiguous block of committed hours
- QSE initially commits
- RUC extends commitment

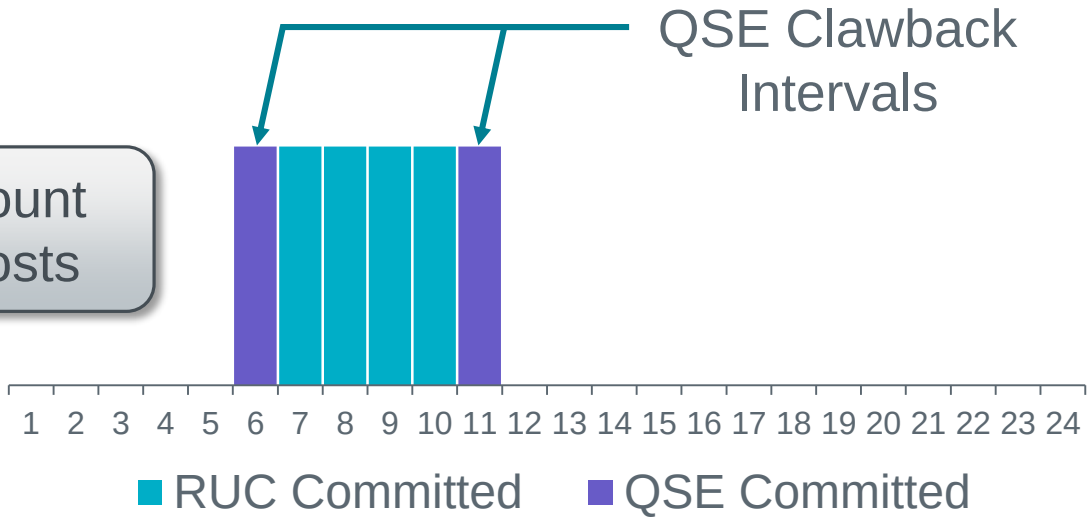
RUC Guaranteed Amount
will not include Startup Costs



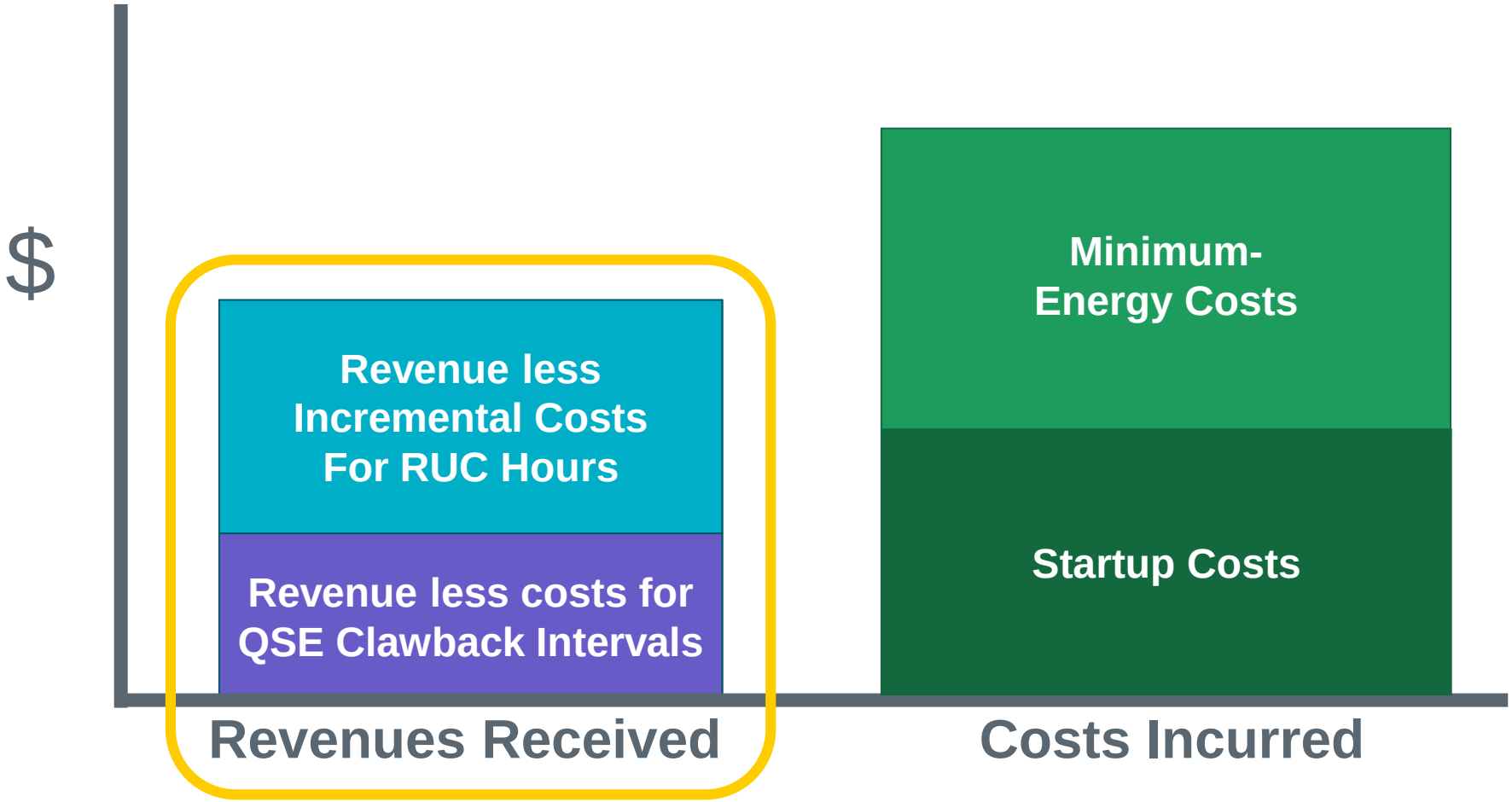
Startup Cost Eligibility

- One Start per contiguous block of committed hours
- RUC initially commits
- QSE extends commitment

RUC Guaranteed Amount will include Startup Costs

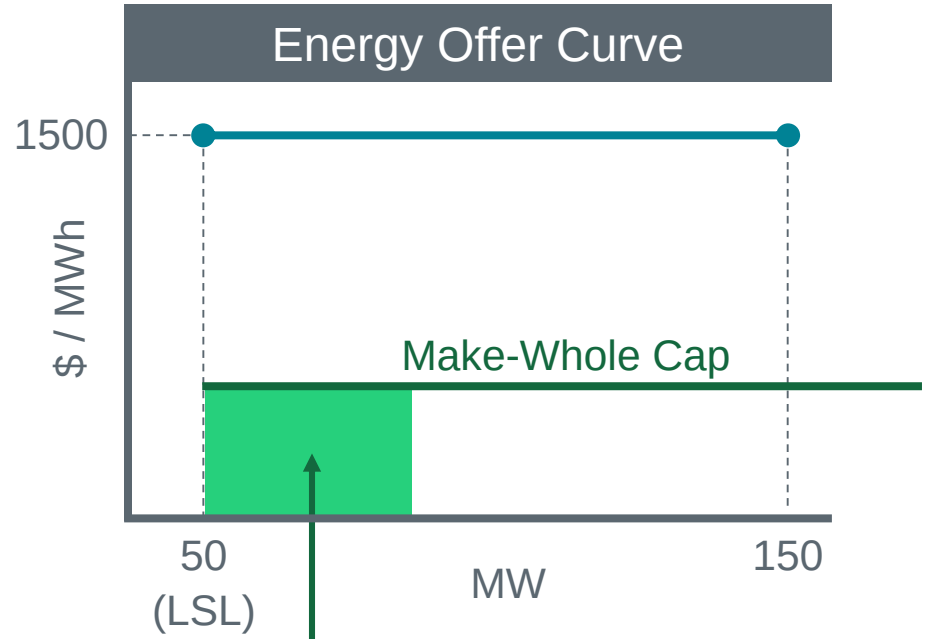


Must divide Real-Time Revenue into two types



Revenue less Incremental Costs for RUC Hours

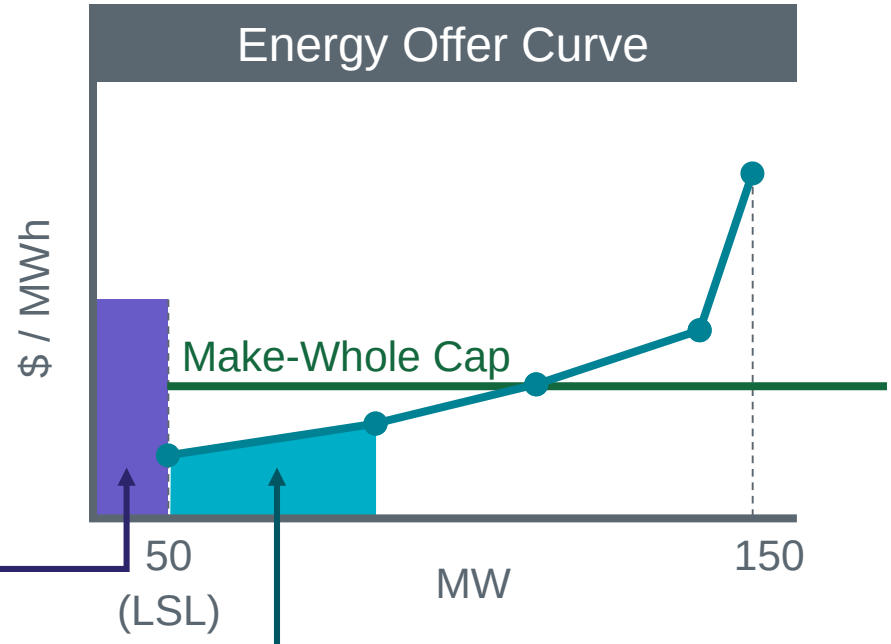
- Incremental Costs taken from Energy Offer Curve
- Subject to Make-Whole Cap



Average Incremental Energy Cost = Area / (MW Output above LSL)

Revenue less costs for QSE Clawback Intervals

- Incremental Costs taken from Energy Offer Curve
- Subject to Make-Whole Cap



Minimum-Energy Cost

Average Incremental Energy Cost = Area / (MW Output above LSL)

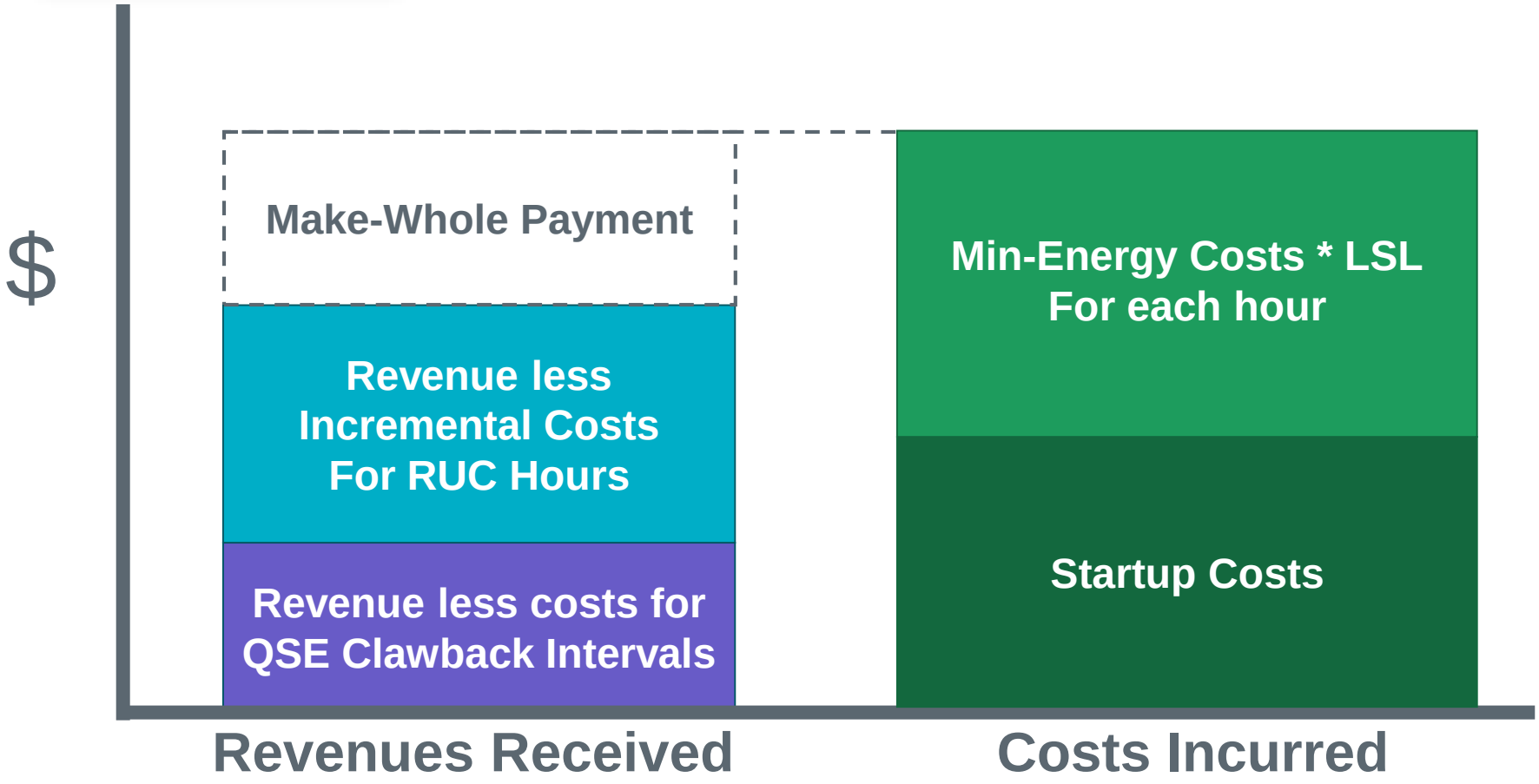
Scenario 3

Generation Resource BIGGEN1 starts in Hour 6 and shuts down in Hour 11

	Revenue less Incremental Costs for RUC Hours	Revenue less Costs for QSE Clawback Intervals
Hour 6		$0
Hour 7	$1000	
Hour 8	$1900	
Hour 9	$2000	
Hour 10	$1000	
Hour 11		$0
Total	$5900	$0

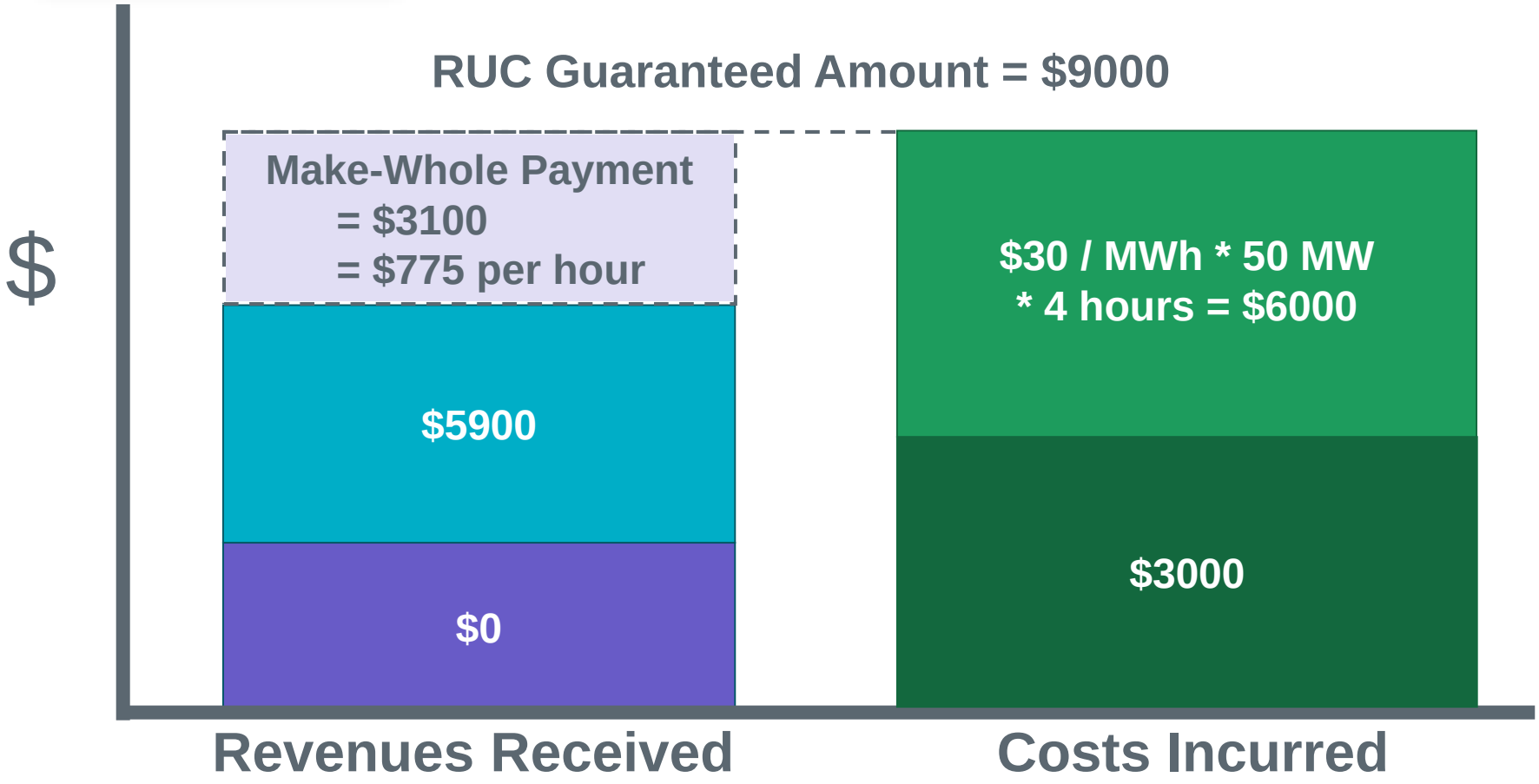
Scenario 3

What if revenues are less than costs?



Scenario 3

What if revenues are less than costs?

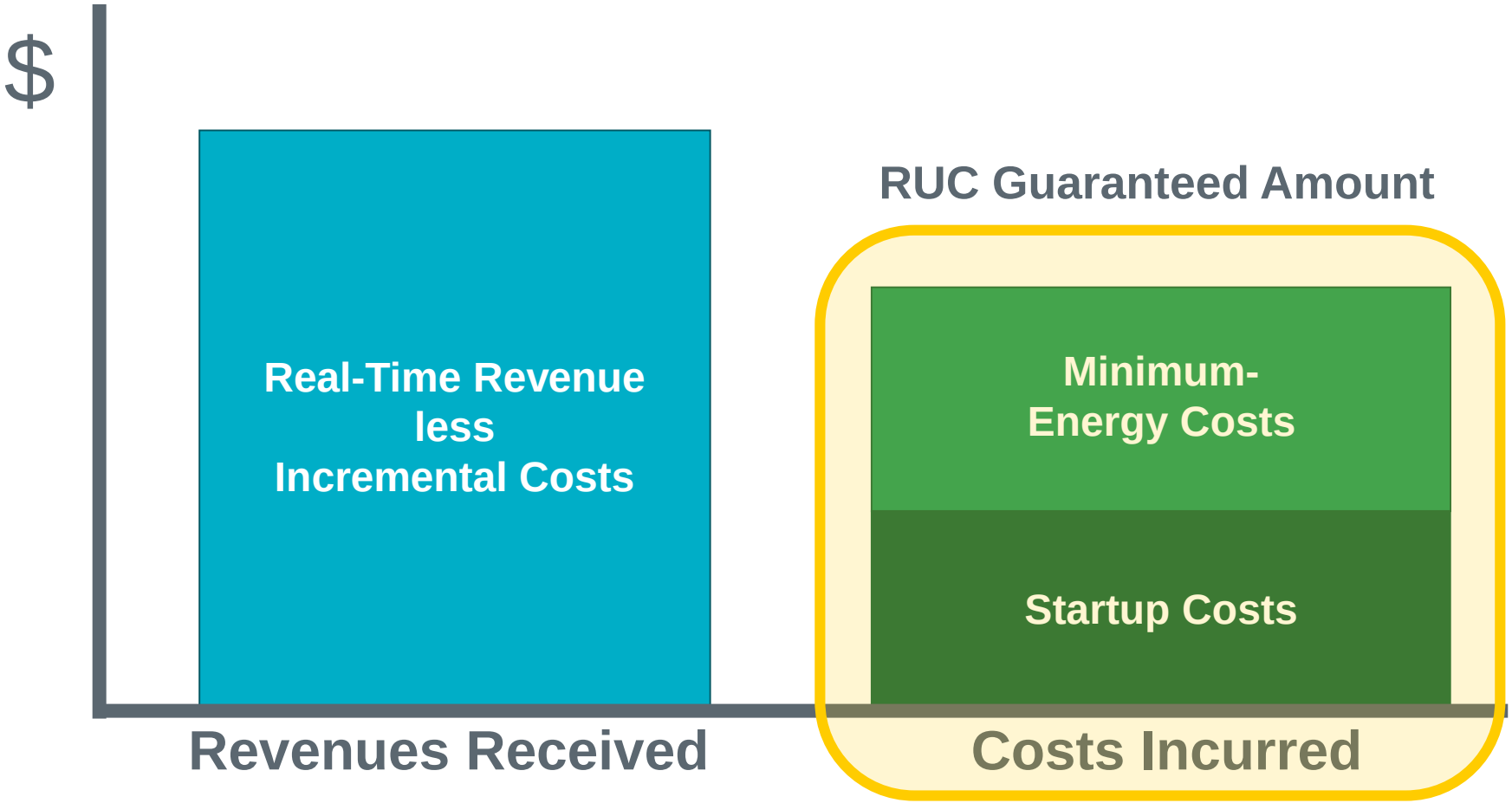


Scenario 3

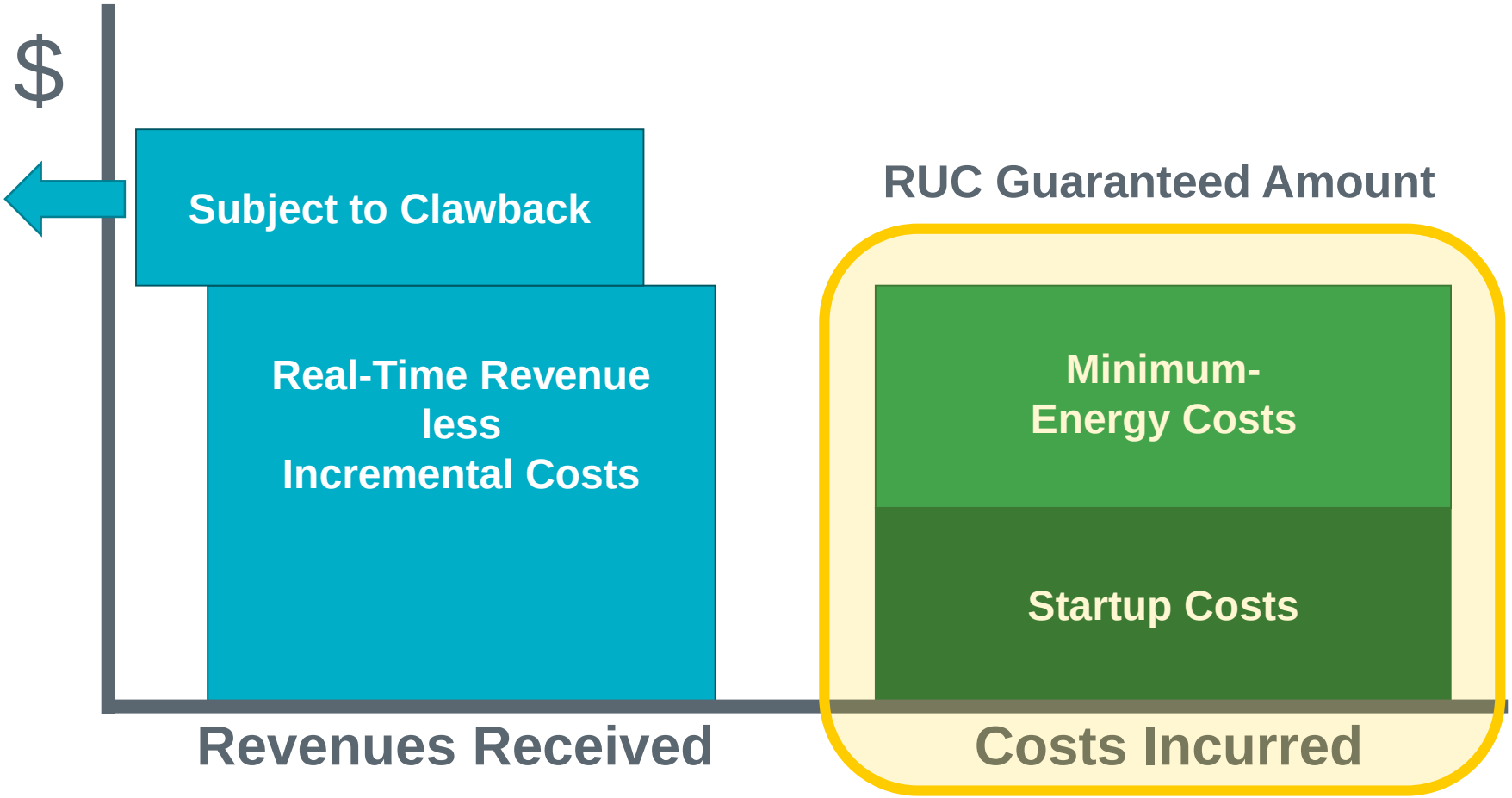
Generation Resource BIGGEN1 is Committed by RUC for 4 hours

	Real-Time Energy Imbalance	Make-Whole Payment	Total
Hour 6	$500	N/A	$500
Hour 7	$1000	$775	$1775
Hour 8	$2800	$775	$3575
Hour 9	$3020	$775	$3795
Hour 10	$1000	$775	$1775
Hour 11	$500	N/A	$500
Total	$8820	$3100	$11,920

What if revenues are greater than costs?



What if revenues are greater than costs?



Clawback amount depends on circumstances

	Three-Part Supply Offer in DAM	No Three-Part Supply Offer in DAM
Clawback Percentage for RUC hours	50%	100%
Clawback Percentage for QSE Clawback Intervals	0%	50%

Don’t forget – the QSE may have Opted Out

Operational Conditions

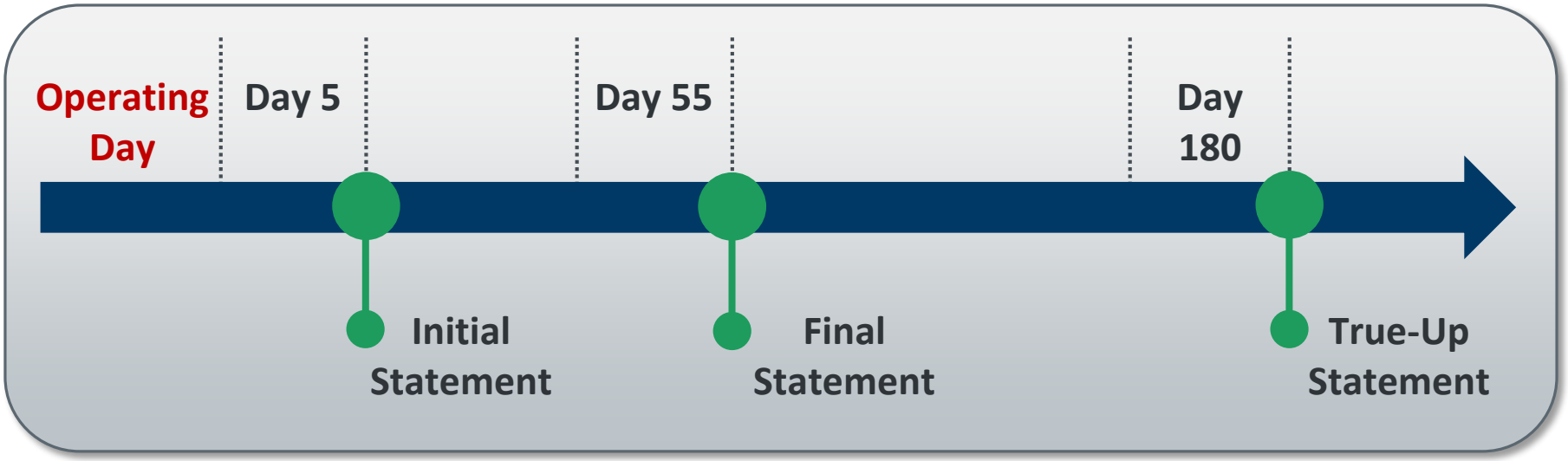
- ONOPTOUT Resource Status
  - COP
  - Telemetry
- Must have run resource if available
- May have provided ancillary services

Financial Impacts

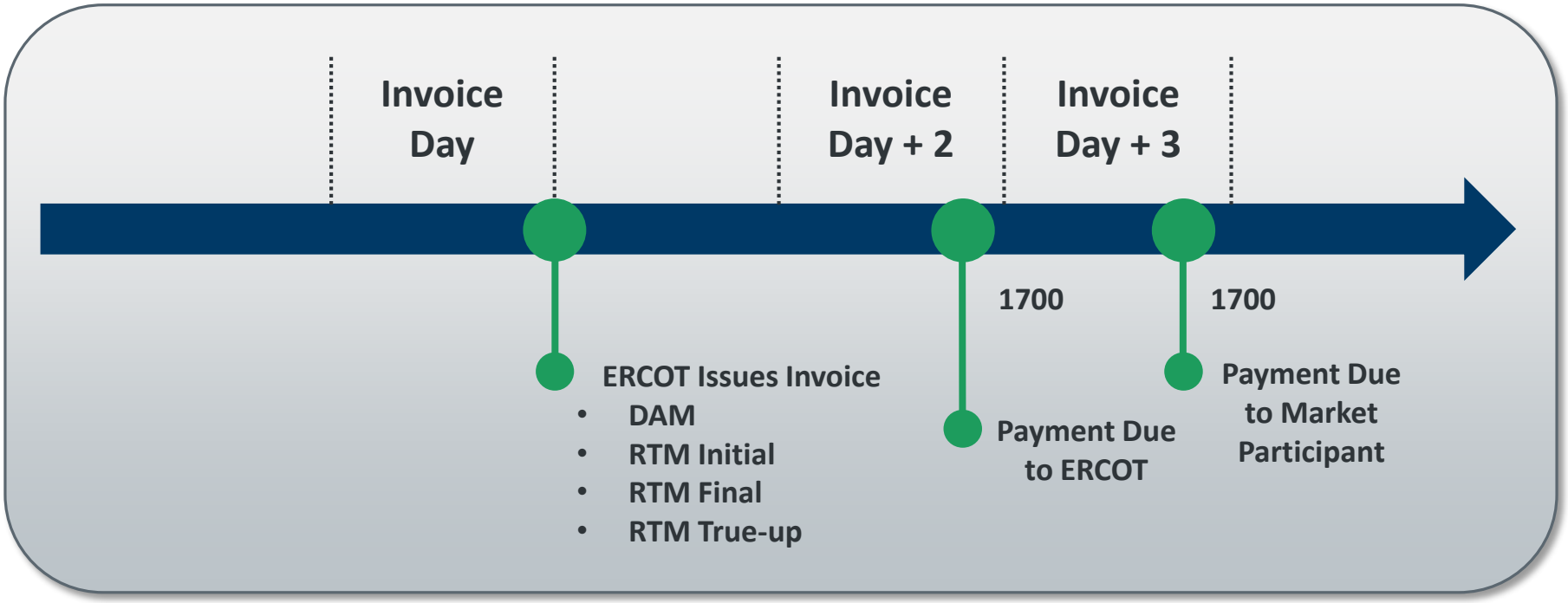
- No RUC Make-Whole Payments or Clawback Charges apply
- QSE chose how to price the Energy Offer Curve

Real-Time Market Settlement Statements

- Payments due and Charges incurred
- Posted to MIS Certified Area



Single Daily Settlement Invoice



You've learned about ...

- Real-Time Dispatch and Formation of Dispatch Limits
- The Mind of SCED (Security Constrained Economic Dispatch)
- Load Frequency Control and Primary Frequency Response
- Provision and Deployment of Ancillary Services
- Real-Time Settlements

This completes Resource 301!

You should now be able to …

- Summarize how ERCOT utilizes Resources to meet reliability goals
- Delineate the responsibilities of Resource Entities and QSEs in managing Resources
- Explain how Resource constraints are formed and predict how they impact market solutions
- Compare and contrast how Resources are utilized in Day-Ahead and Real-Time Operations
- Illustrate financial outcomes of the markets and evaluate strategies for offering resources.

Accessing additional information

ERCOT Protocols
http://www.ercot.com/mktrules/nprotocols/

ERCOT Training
http://www.ercot.com/services/training/

ERCOT Account Management Services
ErcotAccountManagers@ercot.com

ERCOT Credit
ERCOTCredit@ercot.com

ERCOT Market Education Contact
Training@ercot.com

Got Feedback?

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https://www.surveymonkey.com/r/ERCOTILT