Methodology for Implementing Operating Reserve Demand Curve (ORDC) to Calculate Real-Time Reserve Price Adder

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Document Revisions

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09/19/2013	0.1	Initial draft	ERCOT Staff
10/03/2013	0.2	Second draft	ERCOT Staff

PROTOCOL DISCLAIMER

This document describes ERCOT systems and the response of these systems to Market Participant submissions incidental to the conduct of operations in the ERCOT Texas Nodal Market and is not intended to be a substitute for the ERCOT Protocols (available at http://www.ercot.com/mktrules/nprotocols/current), as amended from time to time. If any conflict exists between this document and the Protocols, the Protocols shall control in all respects.

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1. PURPOSE

Protocol Section 6.5.7.3, Security Constrained Economic Dispatch, requires the ERCOT Board to approve ERCOT's methodology for implementing the Operating Reserve Demand Curve (ORDC) to calculate the Real-Time reserve price adders. Additionally, the ERCOT Board must approve the parameters to be used in the methodology.

For each Security-Constrained Economic Dispatch (SCED) process, ERCOT calculates a Real-Time On-Line Reserve Price Adder (RTORPA) and a Real-Time Off-Line Reserve Price Adder (RTOFFPA) based on the On-Line and Off-Line available reserves in the ERCOT System and the ORDC. The On-Line Reserve Price Adder is added to the Real-Time Locational Marginal Prices (LMPs) to determine the Real-Time Settlement Point Prices. The price after the addition of RTORPA to LMPs approximates the pricing outcome of Real-Time energy and Ancillary Service co-optimization since RTORPA captures the value of the opportunity cost of reserves based on the defined ORDC. An Ancillary Service imbalance Settlement is done based on Protocol Section 6.7.4, Real-Time Ancillary Service Imbalance Payment or Charge, to make Resources indifferent to the utilization of their capacity for energy or Ancillary Service reserves.

This document describes:

- the ERCOT Board-approved methodology that ERCOT uses for determining the Real-Time reserve price adders based on ORDC.
- the ERCOT Board-approved parameters for determining the Real-Time reserve price adders and effective date.

2. BACKGROUND

The concept of the "Interim Solution B+" was initiated by a paper by William Hogan, "Electricity Scarcity Pricing through Operating Reserves: An ERCOT Window of Opportunity,"[1] which was filed with the Public Utility Commission of Texas (PUCT) by GDF Suez on November 14, 2012. The paper emphasized the importance of an Operating Reserve Demand Curve (ORDC) in improving Real-Time scarcity pricing in the ERCOT market. The proposed approach involved the Real-Time co-optimization of energy and Ancillary Services.

Preliminary analysis of the timeframe for implementing Real-Time co-optimization of energy and Ancillary Services indicated that it could not be done quickly. ERCOT contacted Professor Hogan to determine the validity of modifying the existing energy offer floors as an interim solution. This approach was labeled as "Interim Solution A." The resulting collaboration produced a calculation based on Loss of Load Probability (LOLP), Value of Lost Load (VOLL) and the level of available reserves in Real-Time, which was labeled as "Interim Solution B."

[1] W. Hogan, "Electricity Scarcity Pricing through Operating Reserves: An ERCOT Window of Opportunity," Mossavar-Rahmani Center for Business and Government, Harvard Kennedy School, November 1, 2012, available at http://www.hks.harvard.edu/fs/whogan/Hogan_ORDC_110112r.pdf.

Both interim solutions were presented and discussed at a PUCT workshop held on January 24, 2013.

During the January 24, 2013 workshop, concerns were raised about "Interim Solution B" in terms of negative market behavior that the proposal could incentivize. To address these concerns, a modified approach was proposed, "Interim Solution B+," which added an Ancillary Service imbalance Settlement to the "Interim Solution B" approach. The Protocols require ERCOT to implement an ORDC without implementing Real-Time co-optimization of energy and Ancillary Services. This document describes "Interim Solution B+ as the methodology for developing the ORDC and the methodology for determining the reserve price adders using the ORDC. It also lists the values of the parameters to be used.

3. REAL-TIME CO-OPTIMIZATION OF ENERGY AND ANCILLARY SERVICES

Real-Time co-optimization of energy and Ancillary Services does result in the appropriate valuation of energy during periods when demand is high and operating reserves are low. This valuation is accomplished through the utilization of an ORDC that results in the price of energy reflecting the opportunity cost of reserve scarcity. The current ERCOT market includes co-optimization in its organized forward Day-Ahead Market (DAM) without an ORDC, while the Real-Time spot market does not include co-optimization of energy and Ancillary Services. The Real-Time spot market only prices energy and does not include the opportunity cost of operating reserves.

The Real-Time energy and Ancillary Service co-optimization proposal utilizes ORDCs to create appropriate scarcity prices. In the current ERCOT Real-Time spot market, demand is inelastic and energy and Ancillary Service co-optimization is not performed. Resource energy offers or the administrative Power Balance Penalty Curve (PBPC) can set the price at or near the System-Wide Offer Cap (SWCAP) during scarcity conditions. Presently, the SWCAP is the maximum price that a Resource can offer for energy. The current SWCAP was set to $5,000/MWh on 6/1/2013, will be set to $7,000/MWh on 6/1/2014, and will be set to $9,000/MWh on 6/1/2015. If Real-Time energy and Ancillary Service co-optimization is adopted, then the use of the SWCAP in Real-Time and its inter-relation with the PBPC and VOLL need to be revisited. The design of the ORDC and the price of reserves under scarcity depend on the inter-relation between the PBPC, VOLL, ORDC and SWCAP.

Implementing Real-Time co-optimization requires Ancillary Service providers in the DAM to buy back Ancillary Services at the Real-Time price if such services are not provided in Real-Time. Thus, a Real-Time Ancillary Service imbalance Settlement structure for reserves is a part of the Real-Time energy and Ancillary Service co-optimization solution.

4. INTERIM SOLUTION B+

Preliminary analysis of the timeframe for implementing Real-Time co-optimization of energy and Ancillary Services indicated that it could not be done in the near-term. A "minimum" implementation of co-optimization would only co-optimize Responsive Reserve (RRS) Service with an estimated price tag of $25 million and a timeline of three to four years. A "maximum" implementation would co-optimize RRS, On-Line Non-Spinning Reserve (Non-Spin) Service, Off-Line Non-Spin, Regulation Up (Reg-Up) Service and Regulation Down (Reg-Down) Service with an estimated price tag of $42.5 million and a timeline of three to five years.

In order to provide a more gradual increase in the energy price, leading up to the SWCAP as conditions become scarce in Real-Time, two alternative approaches were proposed, "Interim Solution A" and "Interim Solution B." These approaches were filed with the PUCT on January 24, 2013 under Docket No. 40000, Commission Proceeding to Ensure Resource Adequacy in Texas [item# 369].

The "Interim Solution B" proposal removes the existing energy offer floor requirements from Generation Resources for Ancillary Service, and incorporates the ORDC into the determination of Real-Time prices for energy. The proposal introduces a price adder to the system-wide energy price based on the ORDC, which is an increasing function that values the remaining reserves as a function of the total generation in the system. While both approaches indicated above should create the desired effect of having a more gradual increase in the energy price as conditions become scarce in Real-Time, "Interim Solution B" provides a more accurate approximation of full Real-Time co-optimization of energy and Ancillary Services and will include prices for both energy and Real-Time reserves.

During the January 24, 2014 workshop, concerns were raised about "Interim Solution B". These concerns, which focused on negative market behavior that the proposal could incentivize due to the inconsistency between the increased prices and the Dispatch from the Real-Time market, included:

1. Resources ignoring Dispatch Instructions to "chase" the higher energy prices;
2. Entities reducing Real-Time energy offers to values below costs in order to offset possible inconsistencies with the DAM; and
3. Entities needing to buy back DAM energy awards in Real-Time at a higher cost due to the potential inconsistencies.

The utilization of an Ancillary Service imbalance Settlement was developed to address these negative incentives. The "Interim Solution B" combined with the Ancillary Service imbalance Settlement is what is being referred to as "Interim Solution B+."

There are two key values that are part of "Interim Solution B+." The first value is a price for Real-Time reserves from Load Resources providing RRS and Resources that are participating in SCED. This price serves as the price adder for the Real-Time energy price. In order to address price inconsistency between the Dispatch and the final price, the remaining reserves provided by Resources minus their Ancillary Service obligation are paid this price adder as well. The second value is the price calculated and used in the Ancillary Service imbalance Settlement for Real-Time reserves that are being provided by Off-Line Resources. These are Resources that are not currently available for Dispatch by SCED but could be started from a cold temperature state in 30 minutes and extra offline capacity available in 30 minutes from On-Line Combined Cycle

Trains. The Ancillary Service imbalance Settlement will ensure that Resources are indifferent between providing energy and reserves in Real-Time. This addresses the earlier discussed incentive concerns.

While the incentive concerns were originally raised in regards to "Interim Solution B," it is important to recognize that similar concerns also existed with the energy offer floors there were in place and modified as part of "Interim Solution A." This is specifically true for those Resources which are providing On-Line Non-Spin in Real-Time that have a marginal cost lower than $120/MWh. Such a Resource has the incentive to ignore Dispatch Instructions in order to "chase" the higher energy price whenever the price is greater than their marginal cost. However, an Ancillary Service imbalance Settlement process may be less feasible under an energy offer floor approach due to there not being an explicit price for Real-Time reserves.

5. METHODOLOGY FOR IMPLEMENTING ORDC

The maximum price on the PBPC would be set to SWCAP + 1. The Real-Time spot market clearing process uses the SCED application to dispatch Resources and set prices. For each execution of SCED, the System Lambda of the power balance constraint will be determined and the ORDC will be constructed as LOLP * (VOLL – System Lambda). Since the System Lambda in this equation is not a fixed value and could vary for each SCED execution, the Real-Time ORDC could vary for each SCED execution as well. In short, this approach is needed with the current rules in order to ensure that power balance is given the highest priority. This approach, which uses a modified ORDC for each SCED execution, can result in a reserve price that is near zero and an energy price near SWCAP under scarcity conditions.

Determining the following values is a major part of implementing ORDC to calculate Real-Time Reserve Price Adder:

1. VOLL;
2. LOLP;
3. Real-Time On-Line Reserve Price Adder (RTORPA) and Real-Time Off-Line Reserve Price Adder (RTOFFPA).

5.1. Determine VOLL

The VOLL is a parameter for implementing the ORDC and shall be approved by ERCOT Board.

5.2. Determine LOLP

The key part of "Interim Solution B+" is the determination of LOLP. LOLP depends on many factors, including the probability of forced outages, probability of Load forecast error and probability of wind forecast error. It could also be different for different times of the day and for different months of the year. LOLP at a given reserve level can be interpreted as the probability of the occurrence of an event with a magnitude greater than that reserve level. A minimum contingency level (X) is chosen in order to send an appropriate scarcity price signal to maintain reliability and stability of the system. The LOLP for reserve levels below the minimum contingency level (X) will be set to one. In addition, since ERCOT is at a higher risk of shedding firm Load when reserves fall near or below the minimum contingency reserve level, the LOLP curve is shifted to the right by the minimum contingency level (X) amount. The LOLP curve for a given reserve level (R) is given as follows:

$$\pi(R) = \begin{cases} LOLP(R-X), & R-X \geq 0 \\ 1, & R-X < 0 \end{cases}$$

LOLP is determined by analyzing historic events defined as the difference between the hour-ahead forecasted reserves with the reserves that were available in Real-Time during the Operating Hour. These events are split into twenty-four groups, comprising of four seasons and six time-of-day blocks per day. These groups are used to determine twenty-four distinct normal probability distributions of the events, which will determine the LOLP for the corresponding season and time block. The detailed logic for determining LOLP is described as below:

1) For each Operating Hour in the study period, calculate the system-wide Hour-Ahead (HA) reserve using the snapshot of last Hourly Reliability Unit Commitment (HRUC) for the Operating Hour (at the end of Adjustment Period):

   HA Reserve = RUC On-Line Gen COP HSL - (RUC Load Forecast + RUC DCTIE Load) + RUC Off-Line Gen COP OFFNS Responsibility + RUC On-Line Load COP Non-Spin Responsibility + RUC On-Line Load COP Reg-Up Responsibility + RUC On-Line Load COP RRS Responsibility

2) For each SCED interval in the study period, calculate the system-wide available SCED reserve using SCED telemetry and solution as:

   SCED Reserve = SCED On-Line Gen HSL-SCED Gen Base Point + SCED Off-Line Gen OFFNS Schedule + SCED On-Line Load Telemetry RRS Schedule + SCED On-Line Load Telemetry Reg-Up Responsibility + SCED On-Line Load Telemetry Non-Spin Schedule

3) For each Operating Hour in the study period, calculate the hourly average system-wide SCED reserve by averaging the interval SCED reserve in step 2).

4) For each Operating Hour in the study period, calculate the system wide Reserve Error as:

   Reserve Error = HA Reserve – SCED Reserve (Hourly Average)

5) For each Operating Hour in the study period, allocate it to the corresponding season and time block. All the hours will be split into 24 distribution groups developed for the analysis based on the Season and the time of day:

   - 4 Seasons of
     - Winter (Months 12,1, 2),
     - Spring (Months 3,4,5),

    - Summer (Months 6,7,8) and
    - Fall (Months 9,10,11)
- 6 time-of-day blocks each consisting of 4 hours

6) Calculate the mean (μ) and standard deviation (σ) for each of the twenty-four distinct LOLP distributions using the calculated Reserve Error in step 4). The detail results for 2011 and 2012 are illustrated in Table 1. This hourly error is normally distributed and hence LOLP for a given value reserve level R can be calculated:

$$LOLP\left(\mu,\sigma,R\right)=1-CDF\left(\mu,\sigma,R\right)$$

Where CDF is the Cumulative Distribution Function of the normal distribution with mean μ and standard deviation σ.

Table 1 LOLP distributions by season and time-of-day block for 2011 and 2012

Season	For Hours	μ	σ
Winter (Month 12, 1, 2)	**1-2 and 23-24**	185.14	1217.89
	3-6	76.28	1253.93
	7-10	136.32	1434.64
	11-14	-218.26	1441.00
	15-18	-53.67	1349.52
	19-22	-183.00	1129.31
Spring (Month 3,4,5)	**1-2 and 23-24**	245.76	1174.61
	3-6	460.41	1313.46
	7-10	348.16	1292.36
	11-14	-491.91	1332.05
	15-18	-253.77	1382.60
	19-22	-436.09	1280.47
Summer (Month 6,7,8)	**1-2 and 23-24**	374.88	1503.97
	3-6	1044.81	1252.25
	7-10	339.01	1679.70
	11-14	-695.94	1251.05
	15-18	-270.54	1284.96
	19-22	-730.33	1331.49
Fall (Month 9, 10,11)	**1-2 and 23-24**	15.90	1044.88
	3-6	478.97	1014.02
	7-10	322.65	1036.07
	11-14	-473.16	1293.83
	15-18	-422.21	1246.49
	19-22	-177.76	1231.14

5.2.1. Calculation of R_S and R_{SNS}

R_S is the reserves from Resources participating in SCED plus the Regulation Up and Responsive Reserves from Load Resources. R_{SNS} is equal to R_S plus the reserves from Resources that are not currently available to SCED but could be started from a cold temperature state in 30 minutes and extra offline capacity available in 30 minutes from On-Line Combined Cycle Trains.

[VERSION 1 – Effective pending implementation of NPRR555:]

1) R_S is calculated based on SCED telemetry and solution as:

$$R_S = RTOLCAP = RTOLHSL - RTBP + RTCLRCAP + RTNCLRRRS - RTOLNSRS$$
$$where$$
$$RTOLHSL = (1 - DF) * RTHSL$$
$$RTCLRCAP = RTCLRREG + RTCLRRRS$$

Where

- *RTOLCAP* is the system total Real-Time On-Line capacity of all On-Line Resources for the SCED interval.
- *RTOLHSL* is the system total Real-Time telemetered High Sustained Limits (HSLs) for all Generation Resources available to SCED for the SCED interval.
- *RTBP* is the system total SCED Base Points for all Generation Resources (excluding all Intermittent Renewable Resources (IRRs), Resources with telemetered ONTEST Resource Status and Resources with telemetered Net real power (in MW) less than 95% of their telemetered Low Sustained Limit (LSL)) for the SCED interval.
- *RTCLRCAP* is the system total Real-Time capacity from Controllable Load Resources (CLR) for the SCED interval-it is the sum of telemetered Real-Time Reg-Up and RRS Ancillary Service Schedules for all CLRs.
- *RTNCLRRRS* is the system total Real-Time telemetered Responsive Reserve Schedule from Non-Controllable Load Resources (NCLR) for the SCED interval.
- *RTOLNSRS* is the system total Real-Time telemetered Non-Spin Ancillary Service Schedule for all Generation Resources for the SCED interval.
- *DF* is the discount applied to the Real-Time HSL of Generation Resources.
- *RTHSL* is the system total Real-Time telemetered HSLs for all Generation Resources (excluding all Intermittent Renewable Resources (IRRs), Resources with telemetered ONTEST Resource Status and Resources with telemetered Net real power (in MW) less than 95% of their telemetered Low Sustained Limit (LSL)) for the SCED interval.
- *RTCLRREG* is the system total Real-Time telemetered Regulation Up schedules from Controllable Load Resources for the SCED interval.
- *RTCLRRRS* is the system total Real-Time telemetered RRS schedules from Controllable Load Resources for the SCED interval.

[VERSION 2 – Replaces Version 1 upon implementation of NPRR555:]

1) R_S is calculated based on SCED telemetry and solution as:

$$R_S = RTOLCAP = RTOLHSL - RTBP + RTCLRCAP + RTNCLRRRS - RTOLNSRS$$
$$where$$
$$RTOLHSL = (1 - DF) * RTHSL$$
$$RTCLRCAP = RTCLRBP - RTCLRLSL - RTCLRNS$$

Where

- *RTOLCAP* is the system total Real-Time On-Line capacity of all On-Line Resources for the SCED interval.
- *RTOLHSL* is the system total Real-Time telemetered High Sustained Limits (HSLs) for all Generation Resources available to SCED for the SCED interval.
- *RTBP* is the system total SCED Base Points for all Generation Resources (excluding all Intermittent Renewable Resources (IRRs), Resources with telemetered ONTEST Resource Status and Resources with telemetered Net real power (in MW) less than 95% of their telemetered Low Sustained Limit (LSL)) for the SCED interval.
- *RTCLRCAP* is the system total Real-Time capacity from Controllable Load Resources (CLR) for the SCED interval-it is the sum of telemetered Real-Time Reg-Up and RRS Ancillary Service Schedules for all CLRs.
- *RTNCLRRRS* is the system total Real-Time telemetered Responsive Reserve Schedule from Non-Controllable Load Resources (NCLR) for the SCED interval.
- *RTOLNSRS* is the system total Real-Time telemetered Non-Spin Ancillary Service Schedule for all Generation Resources for the SCED interval.
- *DF* is the discount applied to the Real-Time HSL of Generation Resources.
- *RTCLRBP* is the system total SCED Base Points from Controllable Load Resources for the SCED interval.
- *RTHSL* is the system total Real-Time telemetered HSLs for all Generation Resources (excluding all Intermittent Renewable Resources (IRRs), Resources with telemetered ONTEST Resource Status and Resources with telemetered Net real power (in MW) less than 95% of their telemetered Low Sustained Limit (LSL)) for the SCED interval.
- *RTCLRLSL* is the system total Real-Time telemetered Low Sustained Limit (LSL) from Controllable Load Resources for the SCED interval.
- *RTCLRNS* is the system total Real-Time telemetered Non-Spin schedules from Controllable Load Resources for the SCED interval.

[VERSION 1 – Effective pending implementation of NPRR555:]

2) R_{SNS} is calculated based on SCED telemetry and solution as

$$R_{SNS} = RTOLCAP + RTOFFCAP$$
$$RTOFFCAP = RTOFFHSL + RTNCLRNS + RTCLRNS + RTOLNSRS + RTOFFCCTH$$
$$where$$
$$RTOFFHSL = (1 - DF) * HSL_{GENOFF30}$$

Where

- *RTOLCAP* is the system total Real-Time On-Line capacity of all On-Line Resources for the SCED interval.
- *RTOFFCAP* is the system total Real-Time Off-Line capacity for the SCED interval.
- *RTOFFHSL* is the system total Real-Time Off-Line HSL from Generation Resources for the SCED interval.
- *RTNCLRNS* is the system total Real-Time telemetered Non-Spin schedules from Non-Controllable Load Resources for the SCED interval.
- *RTCLRNS* is the system total Real-Time telemetered Non-Spin schedules from Controllable Load Resources for the SCED interval.
- *RTOLNSRS* is the system total Real-Time telemetered Non-Spin Ancillary Service Schedule for all Generation Resources for the SCED interval.
- *RTOFFCCH* is the total additional capacity available in 30 minutes from On-Line Combined Cycle Trains for the SCED interval, it is the difference between the Real-Time telemetered HSL of the Combined Cycle Configuration that can be On-Line in 30 minutes or less (based on the telemetered configuration and transition times submitted in the RARF) and the HSL that is currently On-Line for all On-Line Combined Cycle trains.
- $HSL_{GENOFF30}$ is the system total Real-Time telemetered HSL of Off-Line and available Generation Resources that can be started from a cold temperature state in 30 minutes for the SCED interval. It includes the Generations Resources providing Off-Line Non-Spin schedules in Real-Time.

[VERSION 2 – Replaces Version 1 upon implementation of NPRR555:]

2) R_{SNS} is calculated based on SCED telemetry and solution as

$$R_{SNS} = RTOLCAP + RTOFFCAP$$
$$RTOFFCAP = RTOFFHSL + RTCLRNS + RTOLNSRS + RTOFFCCTH$$
$$where$$
$$RTOFFHSL = (1 - DF) * HSL_{GENOFF30}$$

Where

- *RTOLCAP* is the system total Real-Time On-Line capacity of all On-Line Resources for the SCED interval.
- *RTOFFCAP* is the system total Real-Time Off-Line capacity for the SCED interval.
- *RTOFFHSL* is the system total Real-Time Off-Line HSL from Generation Resources for the SCED interval.
- *RTCLRNS* is the system total Real-Time telemetered Non-Spin schedules from Controllable Load Resources for the SCED interval.
- *RTOLNSRS* is the system total Real-Time telemetered Non-Spin Ancillary Service Schedule for all Generation Resources for the SCED interval.
- *RTOFFCCH* is the total additional capacity available in 30 minutes from On-Line Combined Cycle Trains for the SCED interval, it is the difference between the Real-Time telemetered HSL of the Combined Cycle Configuration that can be On-Line in 30 minutes or less (based

on the telemetered configuration and transition times submitted in the RARF) and the HSL that is currently On-Line for all On-Line Combined Cycle trains.

- $HSL_{GENOFF30}$ is the system total Real-Time telemetered HSL of Off-Line and available Generation Resources that can be started from a cold temperature state in 30 minutes for the SCED interval. It includes the Generations Resources providing Off-Line Non-Spin schedules in Real-Time.

5.2.2. Calculation of $\pi_S(R_S)$ and $\pi_{NS}(R_{SNS})$

$\pi_S(R_S)$ and $\pi_{NS}(R_{SNS})$ are functions that describe the LOLP at various reserve levels.

1) Calculation of Curve $\pi_S(R_S)$:

$\pi_S(R_S)$ is a function of the Real-Time reserves that should be available in the first 30 minutes of the hour and is intended to capture the LOLP for that level of reserves. The general equation for $\pi_S(R_S)$ is:

$$\pi_S(R_S) = \begin{cases} LOLP_S(R_S - X), & R_S - X \geq 0 \\ 1, & R_S - X < 0 \end{cases}$$

Where

- X in this equation is a minimum contingency level and represents a level of reserves at which ERCOT may need to begin to shed firm Load.
- $LOLP_S$ is the *LOLP* function for the spinning reserve.

$LOLP_S$ is different from the 60 minutes *LOLP* in Table 1, which is calculated based on the hourly error analysis. The reserves are classified into two categories; those that are being provided by Resources in SCED and Load Resources providing RRS and those that are being provided by Resources that are not currently available to SCED but could be started from a cold temperature state in 30 minutes and extra offline capacity available in 30 minutes from On-Line Combined Cycle Trains. Since the first reserve type is available immediately, those reserves are the only ones considered to be available to respond to any event that happens in the first 30 minutes of the hour. All reserve types are then considered to be available to respond to events that happen in the second 30 minutes of the hour. From the hourly error analysis, a mean (μ) and standard deviation (σ) for the 60 minute *LOLP* are determined for each of the different seasons and time blocks. Because the error analysis is hourly, to capture the events within the first 30 minutes for $\pi_S(R_S)$, the μ and σ needs to be scaled to reflect the 30 minute timeframe, with $\delta = 0.5$hour:

$$\mu' = \delta * \mu = 0.5\mu$$

$$\sigma' = \frac{\delta}{\sqrt{\delta^2 + (1-\delta)^2}} * \sigma = 0.707\sigma$$

So the $LOLP_S$ can be calculated based on the 60 minute *LOLP* as follows:

$$LOLP_S(\mu', \sigma', R) = LOLP(0.5\mu, 0.707\sigma, R) = 1 - CDF(0.5\mu, 0.707\sigma, R)$$

24 $\pi_S(R_S)$ curves are developed based on the season and the time of day.

2) Calculation of Curve $\pi_{NS}(R_{SNS})$:

$\pi_{NS}(R_{SNS})$ is a function of all the Real-Time reserves that can be expected to be available with the hour and is intended to capture the LOLP for that level of reserves based on events that happen in an hour. The general equation for $\pi_{NS}(R_{SNS})$ is:

$$\pi_{NS}(R_{SNS}) = \begin{cases} LOLP(R_{SNS} - X), & R_{SNS} - X \geq 0 \\ 1, & R_{SNS} - X < 0 \end{cases}$$

This is similar to $\pi_S(R_S)$ but the key differences here are the types of reserves considered and the μ and σ that are used in calculating LOLP

- The total On-Line and Off-Line applies for the full change in net Load over the hour and there is no scaling adjustments needed for μ and σ in the $\pi_{NS}(R_{SNS})$ calculations
- Again, *X* in this equation is a minimum contingency level

Like $\pi_S(R_S)$, twenty-four individual curves are created for $\pi_{NS}(R_{SNS})$.

5.3. Determination of Price Adder RTORPA and RTOFFPA

Once LOLP is determined, the Real-Time On-Line Reserve Price Adder (RTORPA) and Real-Time Off-Line Reserve Price Adder (RTOFFPA) for each SCED interval can be calculated. RTORPA (a.k.a. P_S) and RTOFFPA (a.k.a. P_{NS}) are functions of the LOLP at various levels of Real-Time reserves, the net value of Load curtailment, and time duration during which the reserves are available. RTORPA and RTOFFPA are determined as follows:

$$RTORPA = P_S = v * 0.5 * \pi_S(R_S) + P_{NS}$$
$$RTOFFPA = P_{NS} = v * (1 - 0.5) * \pi_{NS}(R_{SNS})$$

where

$v = \max(0, VOLL - SystemLambda)$

$R_S = RTOLCAP$

$R_{SNS} = RTOLCAP + RTOFFCAP$

Where *v* represents the net value of Load curtailment and is calculated as the VOLL minus the SCED System Lambda. System Lambda is subtracted from VOLL to reflect the scarcity value of the marginal dispatch capacity and to ensure that the final cost of energy does not go above the VOLL.

6. METHODOLOGY REVISION PROCESS

Revisions to this document shall be made according to the approval process as prescribed in Protocol Section 6.5.7.3, Security Constrained Economic Dispatch.

7. APPENDIX 1: PARAMETERS FOR IMPLEMENTING ORDC

The definition and values of the parameters used in implementing ORDC are as follows:

Parameter	Definition	Unit	Value
VOLL	Value of Lost Load	$/MWh	9000
X	Minimum level at which ERCOT may need to begin shedding firm Load	MW	2000
DF	A discount factor for Generation Resource HSLs		1%
δ	Duration of the first interval of the hour when Non-Spin cannot avoid curtailments	Hour	0.5