Attachment A:
ERCOT BUSINESS PRACTICE

Setting the Shadow Price Caps and Power Balance Penalties in Security Constrained Economic Dispatch

Document Revisions

Date	Version	Description	Author(s)
07/21/2010	0.1	Initial draft	Bob Spangler/ Haso Peljto/Resmi Surendran
08/11/2010	0.11	Added Section 4.0 Power Balance Shadow Price Cap & Appendix, The SCED Optimization Objective Function and Constraints	Bob Spangler/ Haso Peljto/Resmi Surendran
08/18/2010	0.12	Added Transmission Constraint Shadow Price Cap 3.5	Bob Spangler
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03/12/2010	1.14	Added section to address modification to Maximum Shadow Price for Valley import constraint	Resmi Surendran
05/03/2011	2.0	Revision submitted to the ERCOT Board for approval.	R Spangler

Approval Authority

Title: Director, Wholesale Market Operations

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Date ________________________________

PROTOCOL DISCLAIMER

This Business Practice 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 implementation and is not intended to be a substitute for the ERCOT Nodal Protocols (available at http://nodal.ercot.com/protocols/index.html), as amended from time to time. If any conflict exists between this document and the ERCOT Nodal Protocols, the ERCOT Nodal Protocols shall control in all respects.

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1. Purpose

Protocol Subsection 6.5.7.1.11, Transmission Network and Power Balance Constraint Management, requires the ERCOT Board to approve ERCOT's methodology for establishing caps on the Shadow Prices for transmission constraints and the Power Balance constraint. Additionally, The ERCOT Board must also approve the values (in $/MWh) for each of the Shadow Price caps.

The effect of the Shadow Price cap for transmission network constraints is to limit the cost calculated by the Security Constrained Economic Dispatch (SCED) optimization to resolve an additional MW of congestion on a transmission network constraint to the designated maximum Shadow Price for that transmission network constraint. The effect of the Shadow Price cap for the Power Balance Constraint is to limit the cost calculated by the SCED optimization when the instantaneous amount of generation to be dispatched does not equal the instantaneous demand of the ERCOT system. In this case, the cost calculated by SCED to resolve either the addition or reduction of one MW of dispatched generation on the power balance constraint is limited to the maximum Shadow Price for the power balance constraint, which is also referred to as the Power Balance Penalty.

The maximum Shadow Prices for the transmission network constraints and the power balance constraint directly determine the Locational Marginal Prices (LMP) for the ERCOT Real Time Market in the cases of constraint violations.

This Business Practice describes:

- the ERCOT Board approved methodology that the ERCOT staff will use for determining the maximum system-wide Shadow Prices for transmission network constraints and for the power balance constraint, and
- the ERCOT Board approved Shadow Price caps and their effective date.

Additionally, ERCOT may set a maximum Shadow Price for individual transmission network constraints. When ERCOT does so, it will provide the ERCOT Board a description of the constraint, the ERCOT methodology used to establish the maximum Shadow Price and the value of the maximum Shadow Price.

2. Background Discussion

The term Shadow Price as used in a constrained optimization problem in economics, is usually defined as the change in the objective value of the optimal solution of the optimization problem obtained by changing each constraint, one-at-a-time, by one unit. In the SCED process the objective function to be minimized by the SCED optimization engine is the total system dispatch cost required to maintain the system power balance and to resolve congestion of the transmission network as specified in the transmission constraint input set. The term Shadow Price is used in the context of individual constraints, whether a transmission network constraints or power balance constraint. Consistent with the definition of the Shadow Price, in a minimization problem, such as the SCED, the Shadow Prices for the transmission constraints are different for each transmission constraint and they are positive \$/MW amounts defined as increase of the system dispatch costs if a transmission line limit is decreased by one MW. The Shadow Price for the Power Balance constraint represents system costs for serving the last MW of load. The Power Balance Penalty can be either positive (if the system requires additional generation) or negative (if the system requires a reduction in generation). If a constraint is not binding, meaning the constraint has excess capability under the given system conditions, the Shadow Price of the constraint is \$0.00/MWh. On the other hand, if the constraint is binding, meaning it is limiting because the system conditions are such that the constraint limit is exactly met by the SCED selected dispatch pattern, the constraint Shadow Price is a non-zero \$/MW value and when the maximal Shadow Price (i.e. the Shadow Price cap) is reached the constraint will be violated without further increases in the constraint Shadow Price.

In the context of the SCED optimization, the Shadow Prices give rise to the application of a transmission penalty cost and a power balance penalty cost in the SCED objective function that results in an increase in the total system dispatch cost. On the other hand, the transmission network constraint Shadow Prices and the Power Balance Shadow Price directly determine the LMPs (in \$/MWh) calculated in the SCED. The LMPs will be limited because of the Shadow Price cap amounts, expressed in \$/MWh.

For the network transmission constraints, the Shadow Price Cap may vary for each constraint, may be a unique value applicable to all constraints, or may be values unique to subsets of the full constraint set. For the Power Balance constraint, the Shadow Price Cap may be a single value or a value given as a function of the amount of the power balance mismatch (instantaneous generation to be dispatch minus instantaneous demand) in MW.

3. Elements for Methodology for Setting the Network Transmission System-Wide Shadow Price Caps

3.1. Congestion LMP Component

The LMPs at Electrical Buses are calculated as follows:

$$LMP_{EB} = \lambda - \sum_{line} SF_{EB}^{line} \cdot SP^{line}$$

Where:

LMP_{EB}	is LMP at Electrical Bus *EB*
λ	is system lambda (Shadow Price of power balance)
SF_{EB}^{line}	is Shift Factor for Electrical Bus *EB* for transmission *line*

SP^{line} is Shadow Price for transmission *line*.

Note that the Shadow Prices for congested transmission lines are positive, otherwise they are equal zero. The Shift Factors for Electrical Buses on one side of transmission line are negative and for Electrical Buses on the other side of transmission line are positive.

The congestion component of Electrical Bus LMP is:

$$\Delta LMP_{EB}^{cong} = -\sum_{line} SF_{EB}^{line} \cdot SP^{line}$$

and it can be positive or negative depending on sign of Shift Factors. The congestion component of LMP represents a price incentive to generation units connected at that Electrical Bus to increase or decrease power output to manage network congestion. Note that only marginal units (i.e. units that are able to move, not those dispatched at min/max dispatch limits to resolve other constraints or to provide energy to the system) can participate in resolving network congestion and determining the system lambda for a particular iteration of SCED.

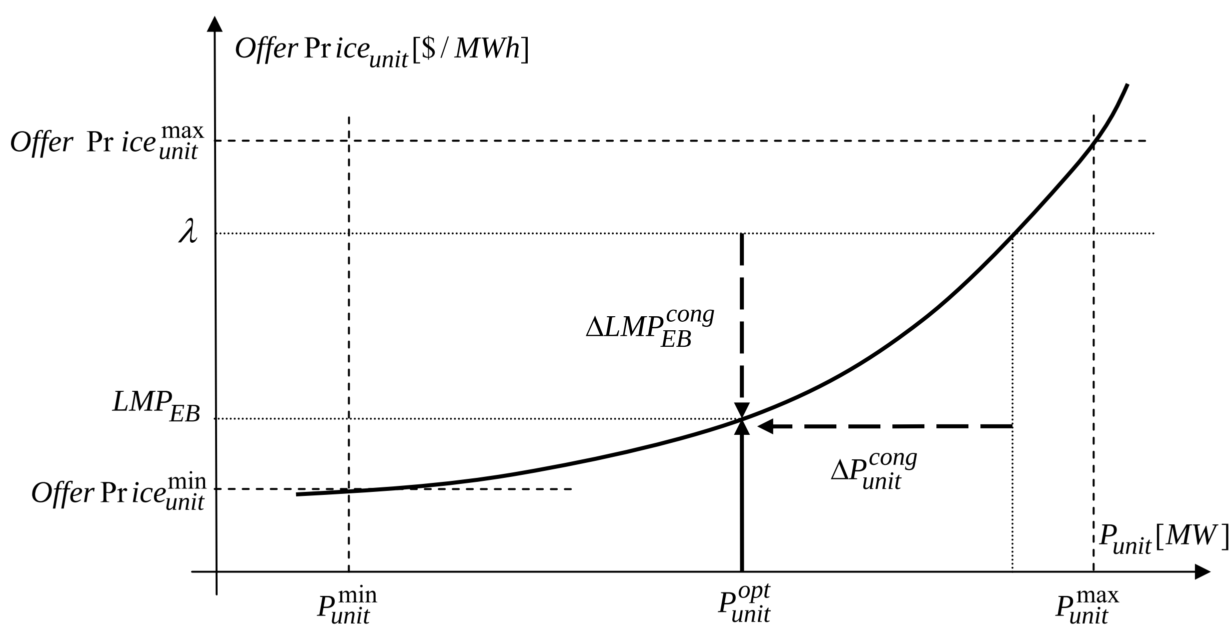
The optimal dispatch from both system (minimal congestion costs) and unit (maximal unit profit) prospective is determined by condition:

$$Offer\ \mathrm{Pr}\,ice_{unit}\,(P_{unit}^{opt}) = LMP_{EB}\,.$$

The generation unit response to pricing signal will result in line power flow reduction in amount:

$$\Delta P^{line} = SF_{EB}^{line} \cdot \Delta P_{unit}^{cong}$$

These relationships are illustrated at the following figure:



3.2. Network Congestion Efficiency

The following three elements of network congestion management determine the efficiency of generating unit participation (as defined above):

- Line power flow contribution ΔP^{line}
- LMP congestion component ΔLMP_{EB}^{cong}
- Unit power output adjustment ΔP_{unit}^{cong}.

The line power contribution is determined by its Shift Factor directly. It may be established that generating units with Shift Factors below specified threshold (10%) are not efficient in network congestion.

The LMP congestion component is main incentive controlling generating unit dispatch. It is determined by Shift Factors and Shadow Prices for transmission constraints:

$$\Delta LMP_{EB}^{cong} = \sum_{line} SF_{EB}^{line} \cdot SP^{line} .$$

Generating units with small Shift Factors (i.e. below Shift Factor threshold) will not be as effective in resolving constraints as will generators with higher shift factors on the constraint. If there is no efficient generating units then Shadow Price must be increased to get enough contribution from inefficient units. Therefore, high Shadow Prices indicate inefficient congestion management.

The maximal value of LMP congestion component $\Delta LMP_{\max}^{cong}$ directly limits the transmission congestion costs:

$$C_{\cos t}^{cong} = \sum_{unit} \Delta LMP_{\max}^{cong} \cdot P_{unit}^{opt} .$$

The efficiency of generating unit contribution can be determined by maximal value of LMP congestion component $\Delta LMP_{\max}^{cong}$ (say \$500/MWh). The maximal Shadow Price for transmission constraint can be established by Shift Factor efficiency threshold and maximal LMP congestion component as follows:

$$SP_{\max} = \Delta LMP_{\max}^{cong} / SF_{threshold}^{efficiency} .$$

The maximal unit power output adjustment $\Delta P_{\max}^{cong}$ will be determined by condition:

$$Offer\,\mathrm{Pr}\,ice_{unit}(P_{unit} - \Delta P_{\max}^{cong}) = LMP_{EB} = \lambda - SF_{threshold}^{efficency} \cdot SP_{\max}$$

3.3. Shift Factor Cutoff

Note: This Shift Factor cutoff is not related to above Shift Factor efficiency threshold used for determination of maximal Shadow Price.

Some generating units can be excluded from network congestion management by ignoring their contribution in line power flows. Note that this exclusion cannot be performed physically, i.e. all units will always contribute to line power flows according to their Shift Factors. Therefore, the Shift Factor cutoff introduces an additional approximation into line power flow modeling.

Since the effect of the Shift Factors below the cut off on the overload are ignored in the optimization, any Shift Factor cutoff will cause additional re-dispatch of the remaining generating units participating in the management of congestion on the constraint. I.e. Generation Resources with Shift Factor above cut off will have to be moved more to account for the increase in overload caused by increasing generation of an inexpensive Resource with positive Shift Factor below cut off and decreasing generation of an expensive Resource with negative Shift Factor below cut off.

The Shift Factor cutoff will cause mismatch between optimized line power flow and actual line power flow that will happen when dispatch Base Points are deployed. This mismatch can degrade the efficiency of congestion management.

The Shift Factor cutoff can reduce volume of Shift Factor data and filter out numerical errors in calculating Shift Factors. Currently the default value of Shift Factor cut off is 0.0001) and is implemented at the EMS to reduce the amount of data transferred to MMS. Any threshold above that level will cause a distortion of congestion management process.

3.4. Methodology Outline

The methodology for determination of maximal Shadow Prices for transmission constraints could be based on the following setting:

a) Determine Shift Factor efficiency threshold $SF_{threshold}^{efficiency}$ (default x%)

b) Determine maximal LMP congestion component $\Delta LMP_{\max}^{cong}$ (default $y/MWh)

c) Calculate maximal Shadow Price for transmission constraints:

$$SP_{\max} = \Delta LMP_{\max}^{cong} / SF_{threshold}^{efficiency}$$

d) Determine Shift Factor cutoff threshold $SF_{threshold}^{cutoff}$ (default z%)

e) Evaluate settings on variety of SCED save cases.

3.5. Current Values for the Transmission Network System-Wide Shadow Price Caps in SCED

The following values will be used in the Nodal Market Trials testing environment, which will allow for evaluation of the results and the potential for general (*i.e.*, for a voltage class) or specific (*i.e.,* for a specific constraint) modifications based on experience. Unless approved otherwise by the ERCOT Board, these Transmission Shadow Price Caps will remain the same upon initiation of the Texas Nodal Market.

Transmission Constraint Shadow Price Caps in SCED

- Base Case/Voltage Violation: $5,000/MW
- N-1 Constraint Violation
    - 345 kV: $4,500/MW
    - 138 kV: $3,500/MW
    - 69 kV: $2,800/MW

3.5.1. Transmission Constraint Shadow Price Cap in SCED Supporting Analysis

Figure 1 is a contour map that shows the relationship between the level of the constraint shadow price cap, the offer price difference of the marginal units deployed to resolve a constraint, and the shift factor difference of the marginal units deployed to resolve a constraint.[1]

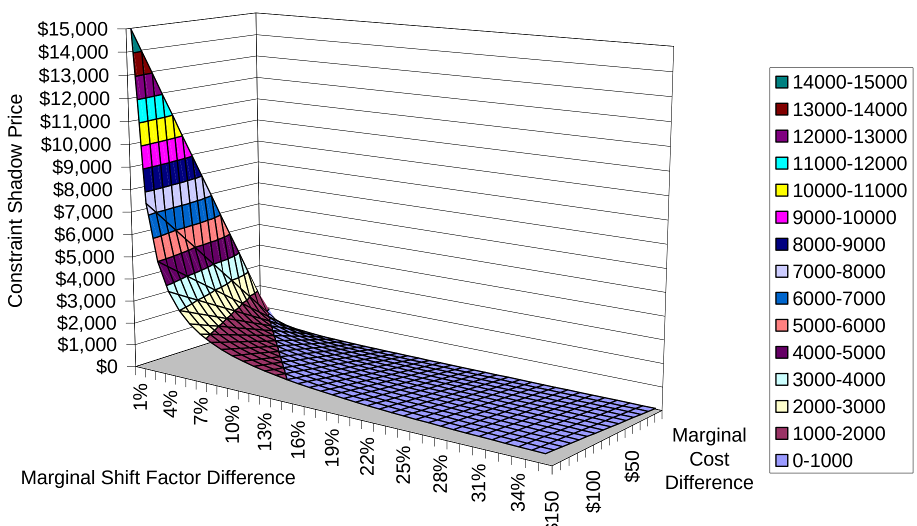


Figure 1

[1] A distributed load reference bus is assumed in this document, and all shift factor values refer to the flow on a constraint (either pre- or post-contingency) assuming an injection at the location in question and a withdrawal at the reference bus.

Figure 2 is a projection of Figure 1 onto the x-axis (*i.e.*, looking at it from the top). These two figures focus on constraint shadow price cap levels, and do not consider the interaction with the power balance constraint penalty factor, which is further discussed in association with Figure 4.

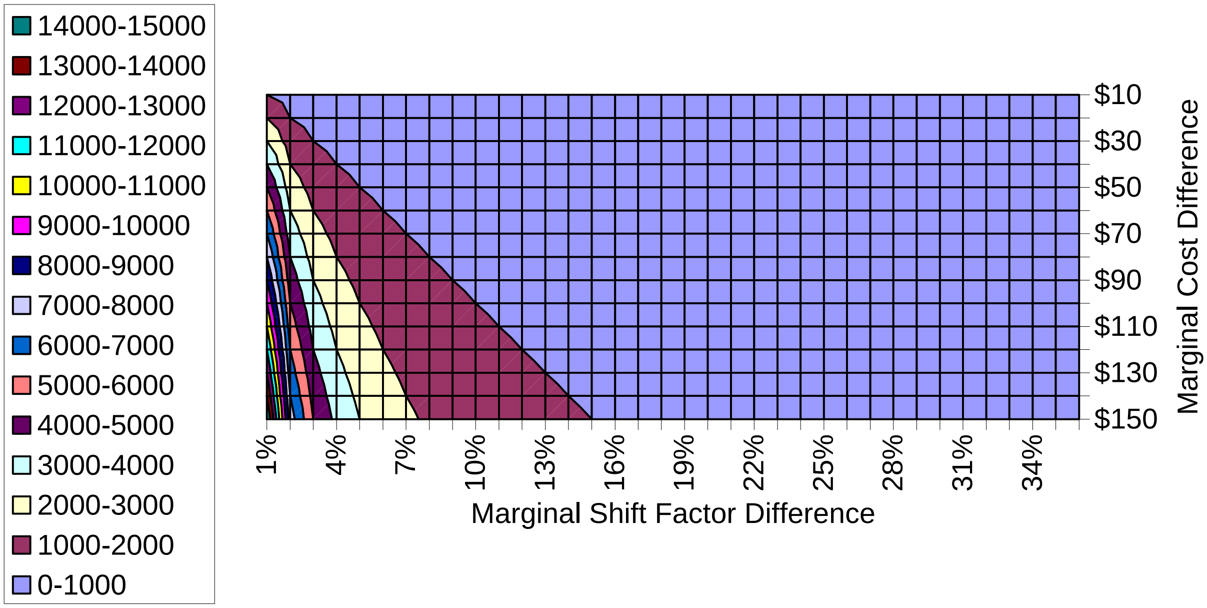


Figure 2

Figures 1 and 2 show that:

- For a constraint shadow price cap of $5,000/MW
  - o Marginal units with an o*ffer price difference* of $50/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units as low as 1%.
  - o Marginal units with an *offer price difference* of $150/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units is as low as 3%.
- For a constraint shadow price cap of $4,500/MW
  - o Marginal units with an *offer price difference* of $45/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units is as low as 1%.
  - o Marginal units with an *offer price difference* of $150/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units is as low as 3.4%.
- For a constraint shadow price cap of $3,500/MW

  - Marginal units with an *offer price difference* of \$35/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units is as low as 1%.
  - Marginal units with an *offer price difference* of \$150/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units is as low as 4.3%.
- For a constraint shadow price cap of \$2,800/MW
  - Marginal units with an *offer price difference* of \$28/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units is as low as 1%.
  - Marginal units with an *offer price difference* of \$150/MWh will be deployed to resolve a constraint when the *shift factor difference* of the marginal units is as low as 5.35%.

Figure 3 shows the maximum offer price difference of the marginal units that will be deployed to resolve congestion with each of the proposed shadow price cap values as a function of the shift factor difference of the marginal units.

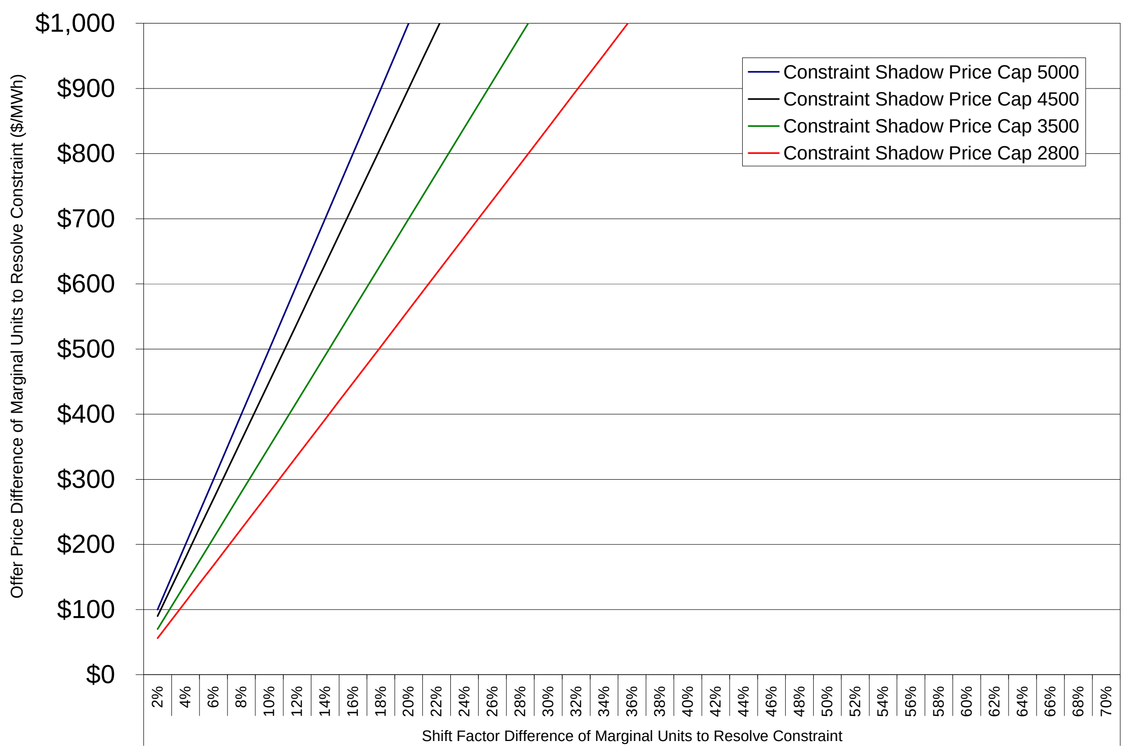


Figure 3

For example, with a shift factor difference of the marginal units of just 2%, the maximum offer price difference of the marginal units that will be deployed to resolve the constraint is $56, $70, $90 and $100/MWh for constraint shadow price cap values of $2,800, $3,500, $4,500 and $5,000/MW, respectively. Similarly, for with a shift factor difference of the marginal units of 60%, the maximum offer price difference of the marginal units that will be deployed to resolve the constraint is $1,680, $2,100, $2,700 and $3,000/MWh for constraint shadow price cap values of $2,800, $3,500, $4,500 and $5,000/MW, respectively.

In some circumstances these constraint shadow price cap values may preclude the deployment of a $3,000/MWh offer. However, it is not possible in the nodal design to establish constraint shadow price caps at a level that will always accept a $3,000/MWh offer and still produce pricing outcomes that remain within reasonable bounds of the PUCT Substantive Rule 25.505(g)(6) $3,000 offer cap. For example, taking the case above where the shift factor difference of the marginal units is just 2%, a constraint shadow price cap of $150,000/MW would be required to deploy $3,000/MWh offers to resolve the congestion (assuming an offer price of zero for the marginal constrained-down unit). In this case, for nodes with a higher shift factor relative to the constraint (regardless of whether the nodes are generation or load nodes), the resulting LMP would be significantly higher than the $3,000/MWh system-wide offer cap if the constraint was irresolvable. For example, a node with a shift factor of -50% would have an LMP with a congestion component of $75,000/MWh from just this one constraint, and even higher if multiple constraints are binding. In contrast, with a $5,000/MW shadow price cap, the congestion component of the LMP of the node with a shift factor of -50% would be $2,500/MW for just this one constraint.

Figure 4 ties together the effect of the proposed constraint shadow price caps and the proposed power balance penalty factor. This figure is shown only for the case of a constraint shadow price cap of $4,500/MW. The purpose of this figure is to demonstrate the circumstances in which the power balance constraint will be violated prior to violating a transmission constraint. In other words, when a unit is constrained-down to manage transmission congestion and the only options available to meet power balance are to either (1) violate the power balance penalty, or (2) violate the constraint, under what circumstances will (1) occur vs. (2)?

Figure 4 shows the following:

- The constraint will be violated prior to violating power balance for offer prices of the constrained-down unit up to $300/MWh in all cases where the shift factor of the constrained-down unit relative to the constraint is less than or equal to 60%.
- Power balance will be violated prior to violating the constraint for offer prices of the constrained-down unit greater than $30/MWh in all cases where the shift factor of the constrained-down unit relative to the constraint is 66% or greater.

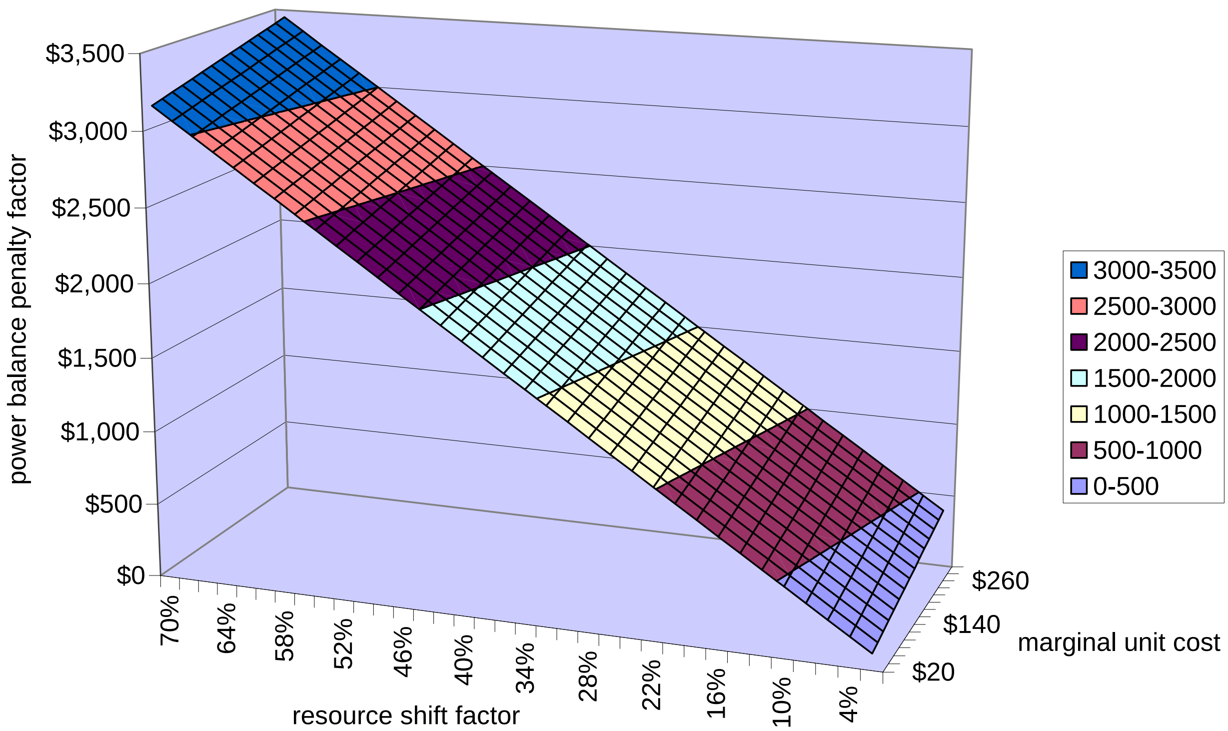


Figure 4

The LMP at an individual node, hub or load zone can exceed the system-wide offer cap in some circumstances. This is most likely to occur when there are one or more irresolvable constraints on the system *and* when overall dispatchable supply on the system is tight. Relatively speaking, it is more likely that individual node prices will exceed the system-wide offer cap than hubs or load zones, but it is possible that hub or load zone prices could exceed the system-wide offer cap. It is not possible in the nodal system to assign constraint shadow price caps and power balance penalty factor values that achieve the desired reliability and efficiency objectives and ensure that all LMPs remain within the bounds of the system-wide offer caps under all circumstances.

Operationally once ERCOT reaches the shadow price cap, ERCOT may use the following method to manage congestion. Steps that may be taken by ERCOT operations to resolve congestion when the transmission constraint is violated in SCED after the Shadow Price reaches the shadow price cap include:

- Formulating a mitigation plan which may include
    - Transmission reconfiguration (switching)
    - Load rollover to adjacent feeders
    - Load shed plans
- Redistribution of ancillary services to increase the capacity available within a particular area.
- Commitment of additional units.
- Re-dispatching generation through over-riding HDL and LDL. [6.5.7.1.10 3(b)]

4. Power Balance Shadow Price Cap

4.1. The Power Balance Penalty

The Power Balance constraint is the balance between the ERCOT System Load and the amount of generation that is dispatched by SCED to meet that load. This Shadow Price for this constraint, also called System Lambda (λ), is the cost of providing one MWh of energy at the reference Electrical Bus. System Lambda, i.e. the Shadow Price for the Power Balance constraint, is equal to the change in the SCED objective function obtained by relaxing the Power Balance constraint by 1MW. The System Lambda is the energy component of Locational Marginal Price at each Settlement Point in ERCOT. The Power Balance Penalty sets the maximum limit for this Shadow Price, i.e. Power Balance Penalty is the maximum cost paid for one addition/less MW of generation to meet the ERCOT system load constraint. This section describes those factors that ERCOT considered in developing the amount of the Power Balance Penalty in $/MW versus the amount of the mismatch and provides the resulting Power Balance Penalty Curve proposed for ERCOT Board approval.

The objective function for SCED is the sum of three components (1) the cost of dispatching generation (2) the penalty for violating Power Balance constraint (3) the penalty for violating network transmission constraints. SCED economically dispatches generation resources by minimizing this objective function within the generator physical limits and transmission limits. Since the Power Balance penalty is the maximum cost for meeting the Power Balance, SCED will re-dispatch generation to meet the Power Balance until the cost of re-dispatching the generation is less than cost of violating the Power Balance. When the cost of re-dispatching the generation resources becomes higher than the cost of violating the Power Balance constraint, then SCED ceases the redispatch of the generation resources and the objective function is minimized with the Power Balance penalty determined by MW amount of the Power Balance constraint violation.

In the ERCOT design, SCED implements the Power Balance Penalty by a step function with up to 10 (Violation MW; Penalty $/MW) pairs. This curve determines the maximum System Lambda for a given amount of the Power Balance Constraint violation. The following section describes the factors that ERCOT considered in developing the amount of the Power Balance Penalty in $/MWh of violation and provides the resulting Power Balance Penalty Curve.

4.2. Factors Considered in the Development of the Power Balance Penalty Curve

ERCOT considered a number of factors in the development of the Power Balance Penalty Curve as described below. The dominant factor in the ERCOT qualitative analysis relates to the use of Regulation Ancillary Service capacity in place of generation capacity provided by the market to resolve the SCED Power Balance constraint violation. ERCOT submits that the Power Balance Penalty Curve presented herein represents a reasonable balance between the loss of the Regulation Ancillary Service capacity used to achieve system power balance and the market value of the energy deployed from these Regulation Ancillary Service Generation Resources.

The factors considered by ERCOT in its qualitative analysis, include the following:

- The amount of regulation that can be sacrificed without affecting reliability,
- The PUCT defined System Wide Offer Cap (SWCAP),
- The expected percentage of intervals with SCED Up Ramp scarcity,
- The expected extend of Ancillary Service deployment by operators during intervals with capacity scarcity, and
- The transmission constraint penalty values.

The following discussion describes the details of these factors as they affect the Power Balance Penalty amounts.

Power Balance mismatch occurs whenever SCED is unable to find a dispatch at a cost lower than the Power Balance constraint Penalty. A Power Balance mismatch can occur under two conditions. One condition occurs when the amount of generation that is dispatched up to each resource's High Dispatch Limits is insufficient to meet the system load. This is referred to as an under generation and the System Lambda will be set by the under generation penalty. The opposite occurs when the amount of generation that is dispatched down to each resource's Low Dispatch Limits is greater than the system load. This is referred to as an over generation and the System Lambda will be set by the over generation penalty. Both of these scenarios are unacceptable because, if left uncorrected by regulation, they result in the operation of the ERCOT system below (under generation) or above (over generation) the system frequency set point (nominally 60 Hertz). In the case of under generation, LFC will dispatch additional Regulation Service to correct the condition and restore system frequency to its set point (nominally 60 Hertz). On the other hand, in the case of over generation, LFC will dispatch reduced amounts of Regulation Service to correct the conditions and restore system frequency to its set point (nominally 60 Hertz). In other words, the Power Balance Penalty Curve acts as if it were an energy offer curve for a virtual Generation Resource injecting the amount of the Power Balance mismatch into the ERCOT system.

Since the actions that cause Regulation Ancillary Service capacity to be deployed to meet the Power Balance constraint reduces the amount of regulation capacity that can be used to maintain control of system frequency, the decision of the pricing of the power balance mismatch represents the value of the trade-off between the reduction in system reliability due to the use of the Regulation AS and the cost to the Load Serving Entities. The ERCOT system is particularly venerable to an inability to maintain system frequency because of the limited interchange capability of ERCOT with the Western and Eastern interconnects and, therefore, the larger the power balance mismatch, the larger the penalty amount.

In ERCOT, the PUCT has determined a maximum offer cap that is representative of supply side pricing associated with the concept of the value of lost load. By PUCT Substantive Rule 25.505, this amount is the High System-Wide Cap and ERCOT selected this amount to serve as the maximum value for the Power Balance Penalty.

Additionally, the Power Balance constraint can also be violated during operational scenarios characterized by generation resource ramp scarcity. SCED calculates dispatch limits (a High Dispatch Limit (HDL) and a Low Dispatch Limit (LDL)) for each resource that represent the amount of dispatch that can be achieved by a Generation Resource at the end of a 5 minute interval at the resource's specified ramp rate given current system conditions and the physical ability of the resource. The ramp rates used in this calculation are referred to as the SCED up Ramp Rate ("SURAMP") and the SCED Down Ramp Rate ("SDRAMP"). A ramp scarcity condition can occur when, for example during morning and evening system ramp intervals, the available capacity for increasing/ decreasing Base Points (the sum of HDL minus current generation/the sum of current generation – LDL) is less than the actual system demand based on the rate at which the system Load is increasing/decreasing. Since the HDL and LDL are calculated based on the physical ramp rate of the resources, they cannot be violated. The likelihood of violation of Power Balance during ramp scarcity increases with the reduction in the capacity available for SCED that in turn depends on the operational philosophies. If Ancillary Services are deployed to maintain enough capacity that can be ramped in each SCED interval then the likelihood of Power Balance violation will be less. On the other hand if Ancillary Services are only deployed to maintain frequency and maintain online capacity and not deployed to maintain enough ramp capacity then the likelihood of Power Balance violation will be more. Along with the violation of the Power Balance Constraint in the over and under generation discussed above, Regulation Ancillary Service will be co-opted in this scenario to compensate for the SCED available capacity shortfall due to these ramp limitations. This scenario is also included in the ERCOT analysis for pricing the Power Balance Penalty.

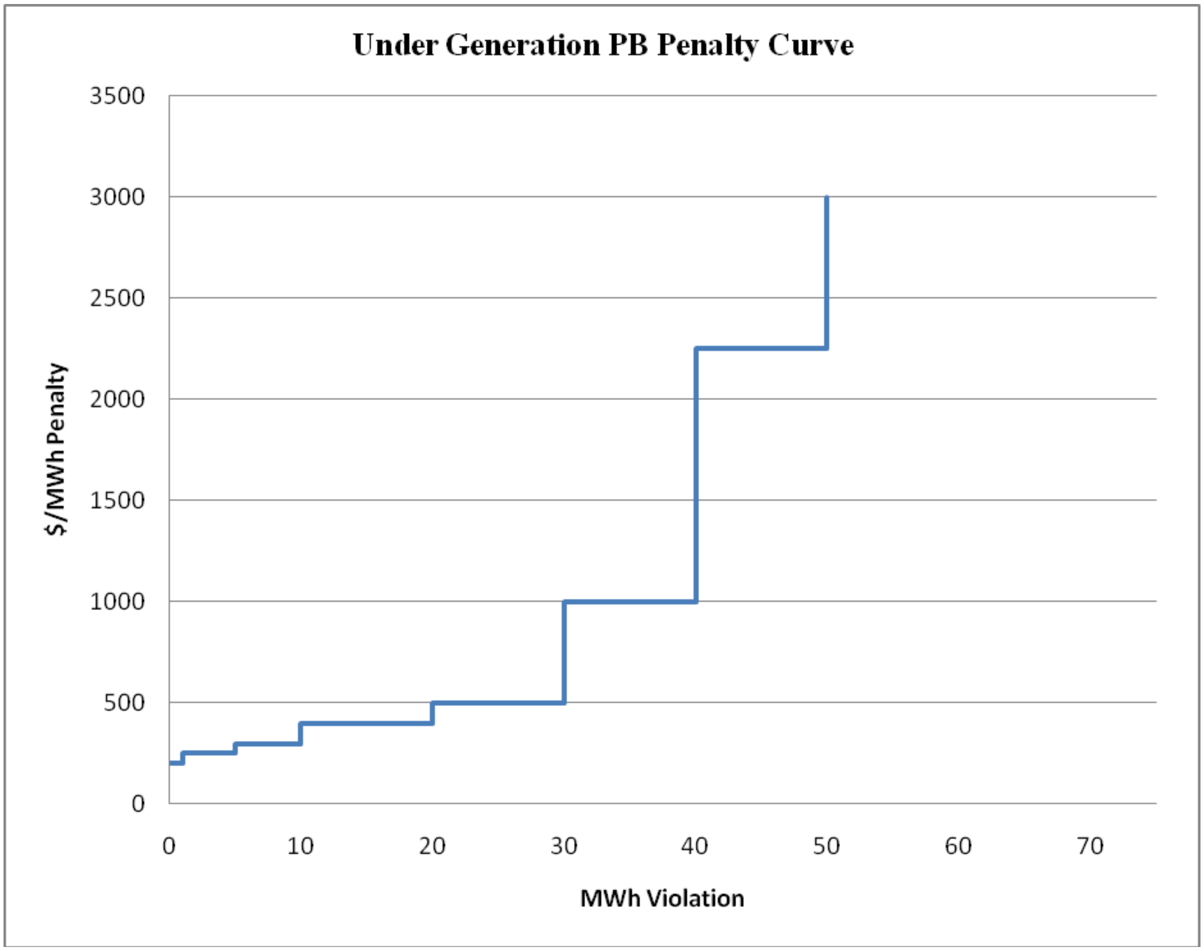
ERCOT also considered the fact that near scarcity, the Power Balance Constraint can become violated as the result of the network transmission constraints that are also binding/ violated at the same time. In this scenario LMPs will depend on the interaction of the Power Balance Penalty with the network transmission constraint Shadow Price caps (refer to the Appendix description of the SCED Energy LMP calculation to view this relationship). Under such condition the relative values of the network transmission constraint penalty and power balance penalty will determine whether resources with positive Shift Factor on the violated constraints will be moved up to meet Power Balance causing the network transmission constraint to become violated or will be moved down to resolve the network transmission constraint violation with a concomitant Power Balance violation.

Additionally, Protocols limit both the Energy Offer Curves (EOC) and the proxy EOC created in SCED to the SWCAP. SCED uses the EOC submitted by a QSE for its Generation Resources subject to the following. A proxy EOC is created in the SCED process if the QSE submitted Energy Offer Curve does not extend from LSL to HSL (in this case SCED extends the submitted EOC as described in Protocol 6.5.7.3 Security Constraint Economic Dispatch). A proxy EOC is also created for Generation Resources operating on an Output Schedule. In this case, the proxy EOC is designed to limit the dispatch of these resources from their Output Schedule amounts by pricing this dispatch at values equal to the System-Wide floor or cap. Since the Power Balance Penalty curve can be characterized as equivalent to a virtual EOC, the relative value of the Power Balance Penalty to the EOCs used by SCED will determine the whether energy will be deployed from the EOC or the Power Balance Penalty curve. If the Power Balance constraint is violated in step one of SCED, then the Power Balance Penalty will set the reference LMP and the submitted and proxy EOCs will then be mitigated at the max of that reference LMP or verifiable cost in the second step of SCED. Consequently, if the Power Balance Penalty Curve provides a gradual ramp to SWCAP then the prices will gradually ramp to the SWCAP instead experiencing a sudden jump to SWCAP.

4.3. The ERCOT Power Balance Penalty Curve

Based on the criteria described in Section 4.2 above, the SCED under generation Power Balance Penalty for use during the Market Trials test period is shown in Figure 5. The SCED over generation Power Balance penalty curve will be set to System Wide Offer Floor. These Power Balance Penalty amounts shown in Figure 5 will be used in the Nodal Market Trials testing environment, which will allow for evaluation of the results and the potential for modifications based on experience. Unless approved otherwise by the ERCOT Board, the Power Balance Penalty Caps will remain the same upon initiation of the Texas Nodal Market.

SCED Under-generation Power Balance Penalty Curve



Where:

MW violation	Violation <1	1 ≤ Violation < 5	5 ≤ Violation < 10	10 ≤ Violation < 20	20 ≤ Violation < 30	30 ≤ Violation < 40	40 ≤ Violation < 50	50 ≤ Violation < 100000
Price $/MWh	200	250	300	400	500	1000	2250	3001

The SCED under generation Power Balance Penalty Curve will be capped at 2251 until the HCAP becomes 3000.

SCED Over-generation Power Balance Penalty Curve

MW violation	Violation <100000
Price $/MWh	-250

Appendix 1

The SCED Optimization Objective Function and Constraints

The SCED optimization objective function is as given by the following:

Minimize { Cost of dispatching generation
+ Penalty for violating Power Balance constraint
+ Penalty for violating transmission constraints}

which is:

Minimize {sum of (offer price * MW dispatched)
+ sum (Penalty * Power Balance violation MW amount)
+ sum (Penalty *Transmission constraint violation MW amount) }

The objective is subject to the following constraints:

- Power Balance Constraint
  sum (Base Point) + under gen slack – over gen slack = Generation To Be Dispatched
- Transmission Constraints
  sum(Shift Factor * Base Point) – violation slack ≤ limit
- Dispatch Limits
  LDL ≤ Base Point ≤ HDL

Based on the SCED dispatch the LMP at each Electrical Bus is calculated as

$$LMP_{bus,t} = SP_{demand,t} - \sum_{c} SF_{bus,c,t} \cdot SP_{c;t}$$

Where

$SP_{demand,t}$ = System Lambda or Power Balance Penalty (if a Power Balance violation exists) at time interval "t"

$SF_{bus,c,t}$ = Shift Factor impact of the bus "bus" on constraint "c" at time interval "t"

$SP_{c,t}$ = Shadow Price of constraint "c" at time interval "t"(capped at Max Shadow Price for this constraint).

During scarcity if a transmission constraint is violated then transmission constraint and Power Balance constraint will interact with each other to determine whether to move up or move down a resource with positive SF to the violated constraints if there are no other resources available.

(a) Cost of moving up the Resource = Shift Factor * Transmission Constraint Penalty + Offer cost
(b) Cost of moving down the Resource = Power Balance Penalty

The Resource will be moved down for resolving constraints if (a) > (b).
If (a) < (b) then the Resource will be moved up for meeting Power Balance.

Appendix 2

Day-Ahead Market Optimization Control Parameters

The purpose of the Day-Ahead Market (DAM) is to economically co-optimize energy and Ancillary Service by simultaneously clearing offers and bids submitted by the Market Participants to maximize social welfare while observing the transmission and generation physical constraints. The ERCOT DAM uses a multi-hour mixed integer programming algorithm to maximize bid-based revenues minus the offer-based costs over the Operating Day, subject to transmission security and other constraints as described in Protocol Section 4. The bid-based revenues include revenues from DAM Energy Bids and Point-to-Point (PTP) Obligation Bids. The Offer-based costs include costs from the Startup Offer, Minimum Energy Offer, and Energy Offer Curve of Resources that submitted a Three-Part Supply Offer, as well as the DAM Energy-Only Offers, CRR Offers, and Ancillary Service Offers. The DAM optimization's objective function includes components that represent the bid based revenues and offer based cost and, additionally, penalty cost values that are used to control certain non-economic aspects of the optimization as described below. These penalty values represent costs of constraint violations and they serve two purposes: rank constraints as relative violation priorities and limit the costs of constraint limitations. Based on the Protocol Section 4.5.1(4)(c)(i), the transmission constraint limits needs to be satisfied in DAM and hence the transmission constraint penalty values are set to very high values to ensure that the constraints are not violated in DAM.

The penalty factors used in the Day-Ahead optimization's objective function are configurable and can be set by an authorized ERCOT Operator. Table 2-1 lists the available optimization penalty cost parameters that are controllable by the ERCOT Operator. The values provided for each of these parameters have been determined by ERCOT based on the results of the DAM quality of solution analysis and various DAM stress tests performed by ERCOT and, following the TNMID, may only be changed with the concurrence of the responsible ERCOT Director.

TABLE 2 - 1

Penalty Function & Shadow Price Cap Cost Parameters	
Constraint	Penalty ($/MWh)
Over and Under - Generation Penalty Factors	
Over Generation	5,000,000.00
Under Generation	5,000,000.00
Ancillary Service Penalty Factors	
Regulation Down	3,000,000.00
Regulation Up	3,000,000.00
Responsive Reserve	2,000,000.00
Non-spin Reserve	1,000,000.00
Network Transmission Penalty Factors	
Base case 1-10KV	350,000.00
Base case 10.1-20KV	450,000.00
Base case 20.1-30KV	550,000.00
Base case 30.1-50KV	650,000.00
Base case 50.1-100KV	750,000.00
Base case 100.1-120KV	850,000.00
Base case 120.1-150KV	950,000.00
Base case 150+KV	1,050,000.00
Contingency 1-10KV	300,000.00
Contingency 10.1-20KV	400,000.00
Contingency 20.1-30KV	500,000.00
Contingency 30.1-50KV	600,000.00
Contingency 50.1-100KV	700,000.00
Contingency 100.1-120KV	800,000.00
Contingency 120.1-150KV	900,000.00
Contingency 150+KV	1,000,000.00
Non-thermal (e.g. generic constraints)	1,000,000.00

2.1 Over/Under – Generation Penalty Factors

In the ERCOT DAM an over/under energy supply condition (referred to here as over/under generation conditions) in an Operating Hour within the Operating Day can occur as a result of a strike of energy only block offers or the inherent lumpiness of Generation Resource strikes. The values of the Over/Under Generation Penalty Factors are chosen to allow the DAM clearing engine to select offers that result in the least amount of the over/under generation over the entire Operating Day and additionally, to enforce this constraint at the highest rank order relative to all other constraints. Additionally, the values of the Over/Under Generation Penalty Factors used in the DAM are considerably higher than the Power Balance Penalty Factor used in the SCED since DAM is a unit commitment problem and for it to clear reasonable offers and bids, the value of these penalty factors need to be high enough to reflect the start up and minimum generation cost of the committed resources. SCED, on the other hand, is an economic dispatch problem and hence for it to dispatch reasonable offers, the Power Balance Penalty Factor need only be in the order of the energy offer cost.

2.2 Ancillary Service Penalty Factors

The Ancillary Service penalty factors serve two purposes. The procured amount of an Ancillary Service can be lower than the difference between the amount of the required AS, as specified in the AS Plan, and the amount of the self-arranged AS. The value of the AS penalty factors are chosen to allow the selection of AS offers that result in the least amount of deficit for each given AS over the Operating Day and to assign a priority to the AS constraints relative to the enforcement of the Power Balance and Network Transmission constraints. Additionally, the increasing penalty cost structure from Non-Spin AS to Regulation AS prioritizes the DAM AS procurement as first Regulation Services, then Responsive Reserve Service and lastly Non-Spin Service. In other words multiple offers from the same resource will be considered in the rank order given. Notably however, the AS penalty factors are not used to set the MCPC for each Ancillary Service. Instead, the infeasible AS requirement amounts are reduced to the feasible level and the DAM clearing is rerun so that the price of the last AS awarded MW sets the MCPC for the each Ancillary Service.

2.3 Network Transmission Penalty Factors

The DAM Clearing Engine includes the Network Security Monitor (NSM) application and Network Constrained Unit Commitment (NCUC) application. These applications execute in a loop beginning with a NSM execution followed by a NCUC execution until a secure commitment pattern that maximizes the objective function is achieved (i.e. NSM begins with an estimated initial unit commitment and uses, thereafter, the latest NCUC commitment). The value of the Network Transmission Penalty Factors for each specified voltage level are used in NCUC application to set the rank order for relaxing the base case constraints and the security constrained network transmission constraints by voltage level and to set the rank order for the enforcement of the Network Transmission Constraints relative to the Power Balance and AS requirements. The increasing value of the Network Transmission Penalty Factors for increasing voltage levels assures that base case and security constraint violations are relaxed progressively in the NSM and NCUC applications with the 69 kV constraints being the first relaxed, followed by 138 kV and lastly the 345 kV constraints. This assures that the DAM solution will honor network transmission constraints in the rank order from the 345 kV to the 69 kV voltage level. Additionally, these penalty factors are chosen such that, in each voltage range, the base case violations have a slightly higher penalty factor than the security constrained penalty factors. This assigns a higher priority in the NSM and NCUC to a network transmission base case violation compared to a network transmission security constrained violation. In other words, within the same voltage level, the security constraints are relaxed before the base case constraints.

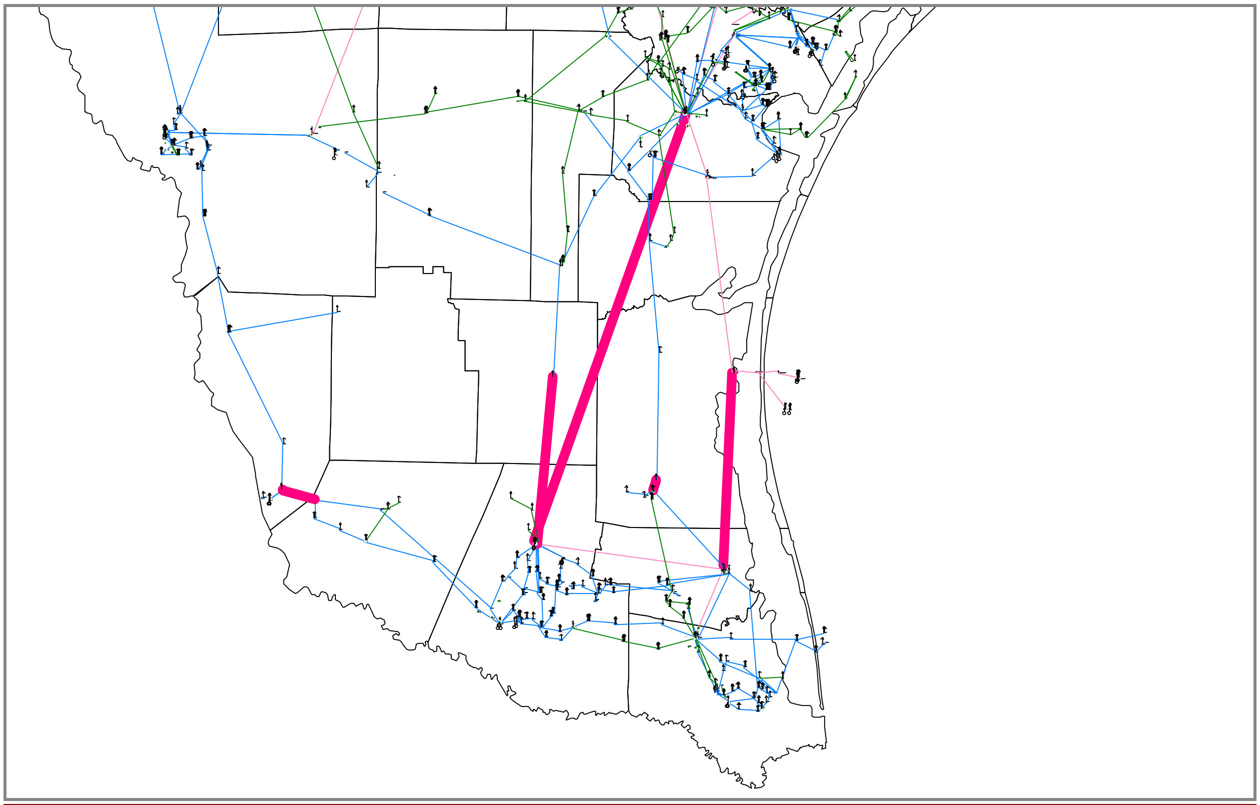
Finally, the Non-Thermal (generic constraint) Penalty Factor assigns these constraints the same priority level in the optimization as the 345 kV security constraints making both less than the 345 kV base case constraints.

The values of the Network Transmission Penalty Factors chosen to enforce the Network Transmission Constraints are considerably higher in DAM when compared to the SCED (Network Transmission Shadow Price Caps) since the DAM is a unit commitment problem and for it to clear reasonable offers and bids, the Network Transmission Penalty Factors need to represent the higher costs associated with a unit start up and generation at minimum energy. The SCED is an economic dispatch problem and hence for it to dispatch reasonable offers; the penalties need only be in the order of energy offer cost.

Appendix 3

Shadow Price Cap for the Valley Import Constraint

The Valley import constraint is different from the average transmission constraints in ERCOT in many ways. As shown in the figure below, it is an interface comprising of five lines into the valley load pocket.



The Valley Import Constraints

Effective management of this constraint is limited to the few Resources that are in the valley. These Resources have shift factor to the Valley import constraint in the range -0.95 to -0.97 under different conditions. Resources elsewhere in the system have minimal shift factors to the Valley import constraint, in the range of 0.03 to 0.045. Even if all the available Resources in the Valley region are on-line and dispatched to the maximum output level, the Valley import constraint might not be resolved under certain scenarios. Under these scenarios, since the Resources in Valley are already at the maximum output level, the Resources outside Valley will not be moved down because economically it is cheaper to violate the Valley constraint than to move the Resources down and violate the Power Balance.

The Valley import is a base case constraint and hence the Shadow Price cap according to section 3.5 is \$5000/MWh. Hence whenever the constraint is violated the LMP of the Electrical Buses in the Valley are increased from system lambda by nearly \$5000. After December 1, 2010, whenever the constraint was violated the South Load Zone price was on averaging around \$1800/MWh. This is a high price for a Load Zone for a constraint to which majority of the loads in the Load Zone have next to no impact. After go-live, whenever the constraint was binding the Shadow Price never went above \$100/MWh indicating the level of Shadow Price cap needed to resolve the constraint as much as possible with the current generation pattern.

Based on the methodology described in section 3.4, the maximum offer from a new or existing Resource and the minimum shift factor in the Valley region needs to be considered to ensure that all available Resources will be dispatched to resolve the constraint as much as possible. Since the Valley import is affected by only a few Resources it is not a competitive constraint and hence the offers from these Resources are mitigated by their verifiable cost. If no verifiable cost is submitted then the maximum Mitigated Offer Curve would be based on 14.5 * FIP. Assuming a very high FIP of \$10/MMBtu, the Shadow Price cap needed to move the offer to maximum output level would be slightly over \$150/MWh (14.5*10/0.95). The maximum mitigated offer cap from a new Resource in Valley region would be (high heat rate * high FIP + O&M) *Multiplier. Based on a high heat rate of 14.5 MMBtu/MWh and corresponding O&M of \$75/MWh, high FIP of \$10/MMBtu, and highest multiplier for capacity Factor of 1.5, the Shadow Price cap for dispatching this new Resource to maximum output level would be around \$350 [(14.5 *10+75)*1.5/0.95].

With a Shadow Price cap of \$350/MWh, if we assume that the hours of overload of the constraint in the last three months, excluding the rare cold event days, continues throughout the rest of the year, a generation Resource in the Valley region will be compensated more than \$50000/MWyear [350*40*4] just from the constraint violation. The Resource will also have the opportunity to profit by operating during the ramp constrained and capacity short intervals. Hence ERCOT recommends \$350/MWh as an appropriate Shadow Price cap for the Valley import constraint.