Title

Calculation of Market Clearing Price for Energy (MCPE) in a zonal type market.

Purpose

To help explain how Market Clearing Price for Energy (MCPE) and Shadow Price (SP) in a zonal type market is calculated. Especially, this white paper elucidates a common puzzle: How can MCPE be higher than the highest bid in the market in some instances?

Definitions from ERCOT Protocols

Market Clearing Price for Energy

The highest price associated with a Congestion Zone for a Settlement Interval for Balancing Energy deployed during the Settlement Interval.

Shadow Price

The cost of an operation to effect a one (1) MW change in a constraint.

Description

The established economic theory and formulas that go into determining "The *highest price* associated with a Congestion Zone for a Settlement Interval for Balancing Energy deployed during the Settlement Interval" are not easy for the layman to understand. However, it doesn't mean that the results cannot be explained in an uncomplicated way. With great but reasonable simplification of the process, the following examples advance step by step and illustrate the results in a way that's easy to follow and understand.

Example 1

First let's look at a simple 3-zone power balance example without congestion. The BES bid information is shown in Figure 1. To simplify the problem, we made the following assumptions:

1. No congestion constraints;
2. Ramp Rate Constraints are automatically satisfied;
3. Resource Plan Constraints are automatically satisfied;
4. BES Bid Constraints are automatically satisfied;
5. Three identical lines (A<–>B, B<–>C, and C<–>A).

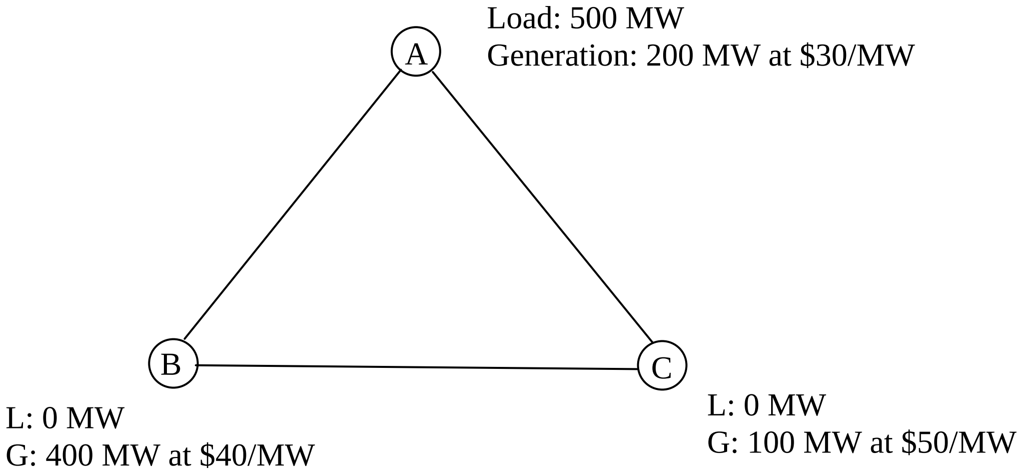

Figure 1

The only constraint we need to solve is power balance constraint: the total amount of generation needs to match the total amount of 500 MW load in zone A (see Figure 1). As there is no congestion, the system will select bids purely based on bid price. It is obvious that the system will deploy all 200 MW from zone A, the cheapest bid in the system, and additional 300 MW from zone B, the next cheapest bid in the system, to satisfy the load at zone A (see Figure 2). For 1 MW of demand increase in any zone, the system will deploy 1 MW of UBES from zone B, as it is the least-cost solution. The marginal cost of such deployment is $40/MW. Therefore, the MCPE for the whole system is $40/MW.

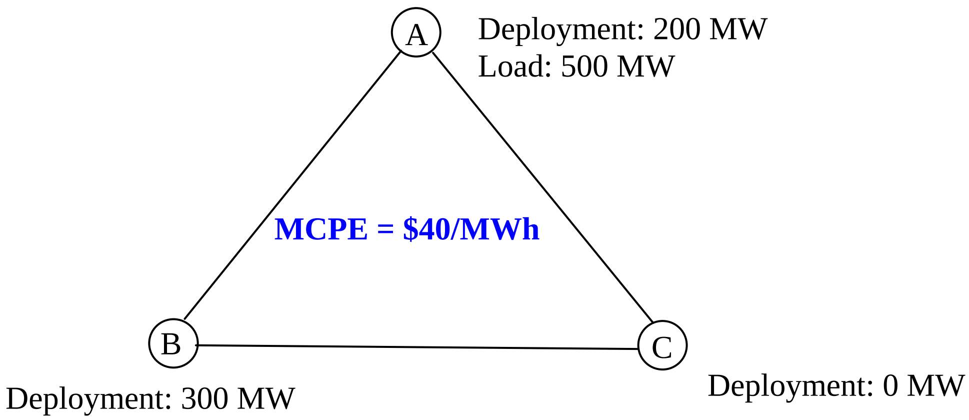

Figure 2

The next question is how the power flow from zone B to zone A will be distributed in the network. There are two routes the power flow can take: (1) the direct line from B to A; and (2) from zone B to zone C and then to zone A. According to Ohm's Law, two thirds of the power will go directly from zone B to zone A, and one third will go from zone B to zone C to zone A (see Figure 3).

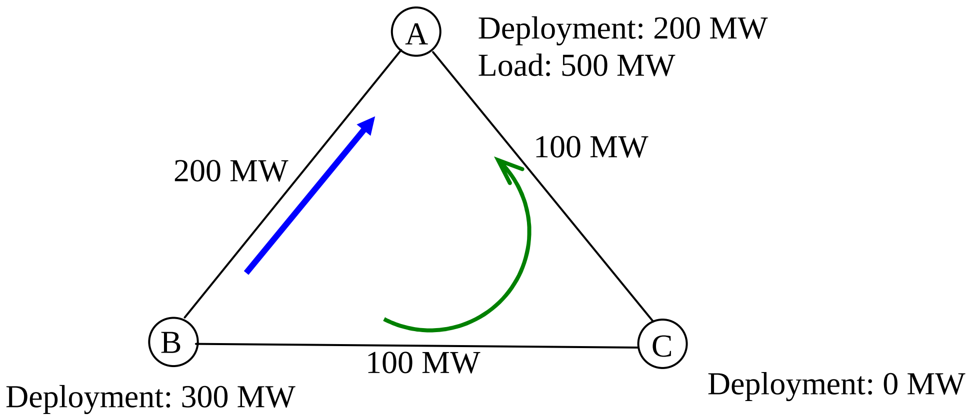

Figure 3

Example 2

Now, consider the simple 3-zone power balance example with a congestion constraint on the line from zone B to zone A (see Figure 4). The BES bid information remains the same as in Example 1. The assumptions for this example are:

1. Flow on line B–>A is limited to 175 MW;
2. Ramp Rate Constraints are automatically satisfied;
3. Resource Plan Constraints are automatically satisfied;
4. BES Bid Constraints are automatically satisfied;
5. Three identical lines (A<–>B, B<–>C, and C<–>A).

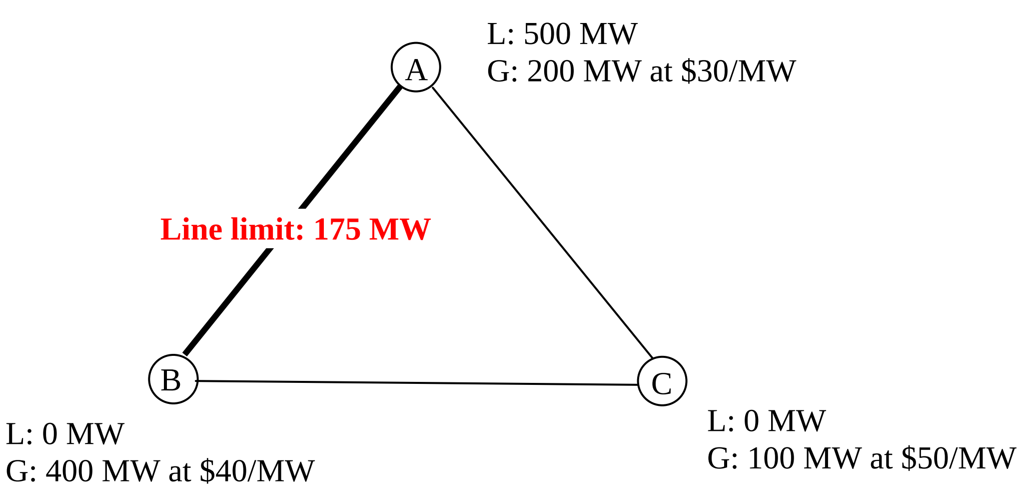

Figure 4

This time, the system cannot simply deploy all 300 MW needed to serve the load at zone A from zone B because doing so would violate the line limit. According to Ohm's Law, 200 MW of energy would flow through B–>A, while 100 MW would flow through B–>C–>A. As shown in Figure 5, the constraint on B–>A would be violated by 25MW (200 – 175 = 25 MW).

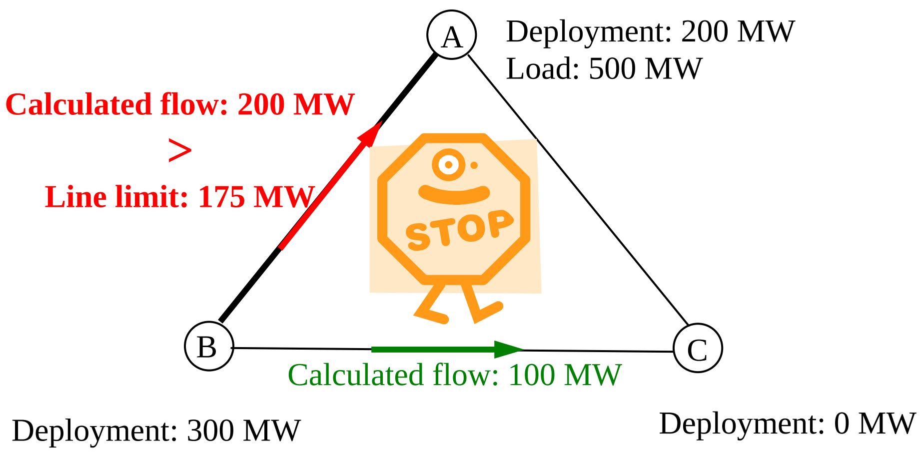

Figure 5

ERCOT must re-dispatch between zone B and zone C to meet both the power balance and the congestion constraints. To do so, we must reduce the deployment from zone B and increase the deployment from zone C. According to Ohm's Law, 1 MW less deployment from zone B will reduce power flow on B–>A by 2/3 MW, while 1 MW more deployment from zone C will increase power flow on B–>A by 1/3 MW. The net effect will be -1/3 MW, i.e., reduce the power flow from zone B to zone A by 1/3 MW. Similarly, 1 MW less deployment from zone B and 1 MW more deployment from zone C will increase the power flow on C–>A by 1/3 MW. The deployment will not change power flow on line B<–>C (see Figure 6).

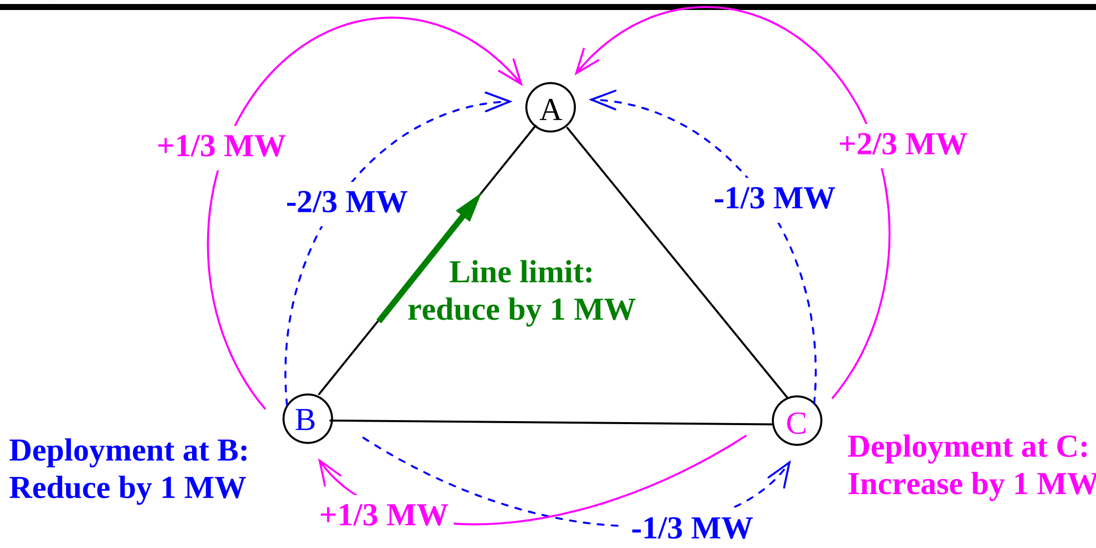

Figure 6

Compared to the original unconstrained deployment, the system must deploy 75 MW less from zone B and 75 MW more from zone C to satisfy both: (1) the power balance constraint to serve all 500 MW of load and (2) the congestion constraint to reduce load on the line from zone B to zone A by 25 MW (see Figure 7).

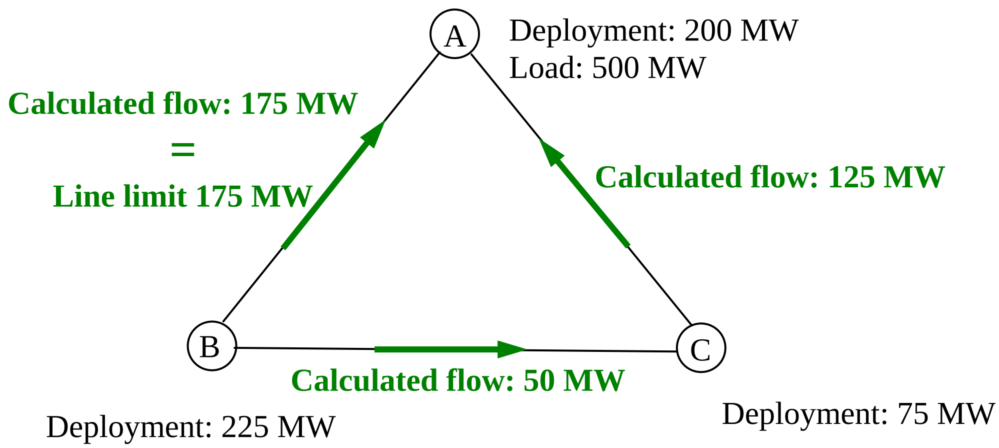

Figure 7

Next, consider the calculation of Shadow Price on the line from zone B to zone A:

According to the definition of Shadow Price, ERCOT must find the cost of an operation to effect a one (1) MW change in a constraint. If we assume the line limit of B–>A changes to 174 MW, we must re-dispatch to reduce the flow on B–>A by one (1) MW. According to Ohm's law, the system will decrease deployment at B by 3 MW and increase deployment at C by 3 MW to effect (reduce) 1 MW of change on B–>A (see

Figure 8). The cost associated with re-dispatching to reduce that 1 MW flow on B–>A will be [(3 MW × $50/MW) - (3 MW × $40/MWh)] / 1MW= $30/MW. Therefore, the cost to relieve 1 MW flow on B–>A, i.e., the Shadow Price of the congestion constraint on line B–>A, is $30/MW.

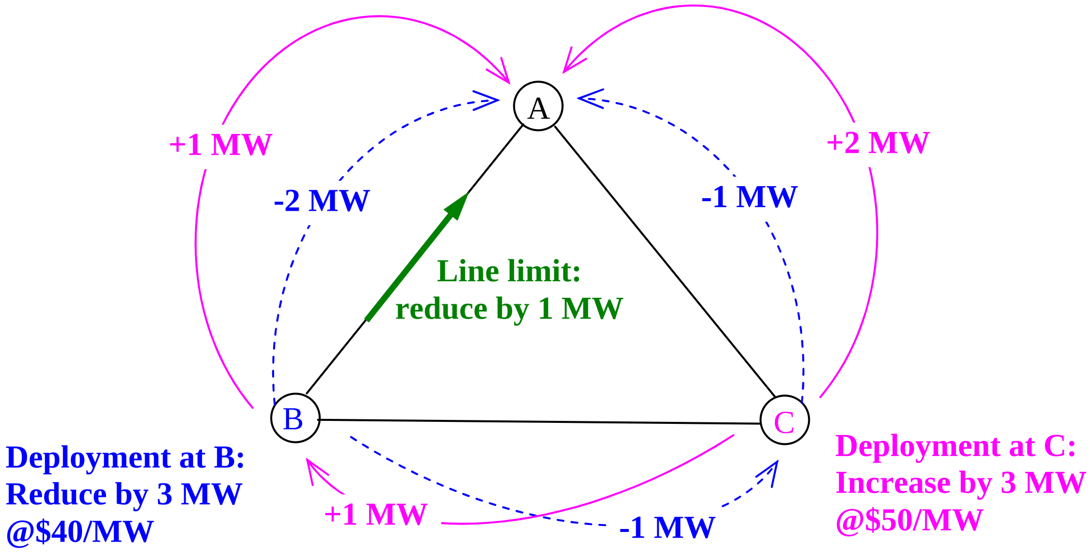

Figure 8

Next, we calculate MCPE for each zone. Energy bid and deployment information for each zone is summarized in Figure 9. According to the definition of MCPE, we must find the highest price associated with a Congestion Zone for a Settlement Interval for Balancing Energy deployed during the Settlement Interval. This "highest price" is defined by established economic theory as the marginal price associated with serving the next 1 MW demand in the zone.

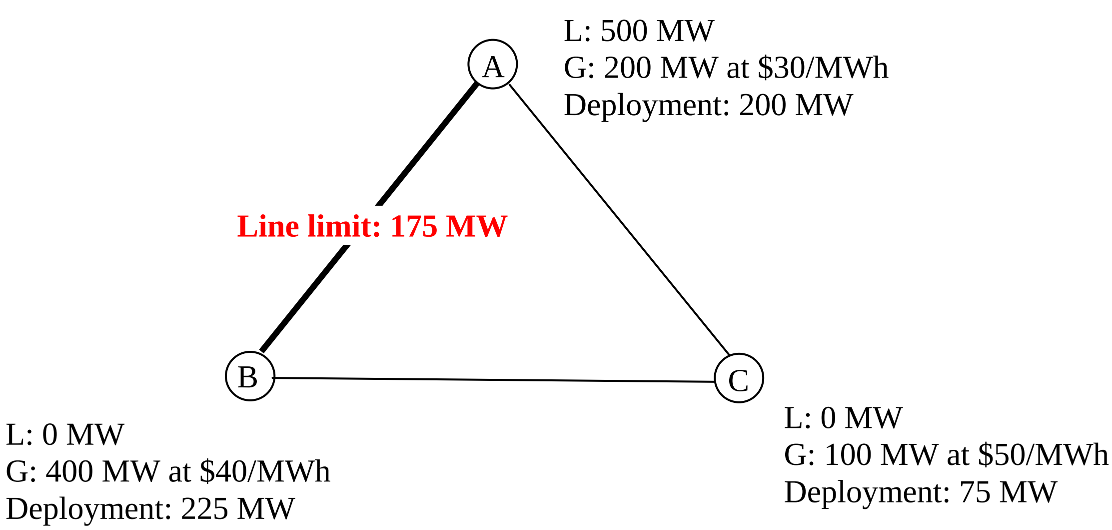

Figure 9

In zone C, there is still 25 MW of generation capability remaining after the UBES deployment. The bid price at zone C is $50/MW. Although additional MWs are available at zone B with a lower bid price than the bid at zone C, they cannot be deployed because doing so would cause the power flow on line B–>A to increase and thus cause congestion. The next bid MW must be deployed from zone C if the demand at zone A increases by 1 MW. The highest price of deployed bids would be $50/MW. Therefore, the MCPE for C is $50/MW.

In zone B, 175 MW of generation capability remains after the UBES deployment. The bid price in zone B is $40/MWh. The system will not consider the available bids from zone C due to their higher bid price. If the demand in zone B increases by 1 MW, the next bid MW will be deployed from zone B. Therefore, the MCPE for zone B is $40/MW.

In zone A, no generation capability remains after the UBES deployment. Any single deployment at either zone B or zone C would cause power flow on B–>A to increase, violating the congestion constraint on B–>A. Therefore, the system must re-dispatch Resources from both zone B and zone C to meet 1 MW of demand increase in zone A. The most economic dispatch is shown in Figure 10: increase deployment from zone C by 2 MW and decrease deployment from zone B by 1 MW. The net flow on line B-A resulting from the re-dispatch remains the same as the line limit, while the flow on C->A increases by 1 MW. Consequently, the 1 MW of demand increase in zone A is served. The cost of this re-dispatch to serve an additional 1 MW Load in zone A is: [(2 MWh × $50/MWh) - (1 MWh × $40/MWh)] / 1MW= $60/MW, which becomes the MCPE for zone A.

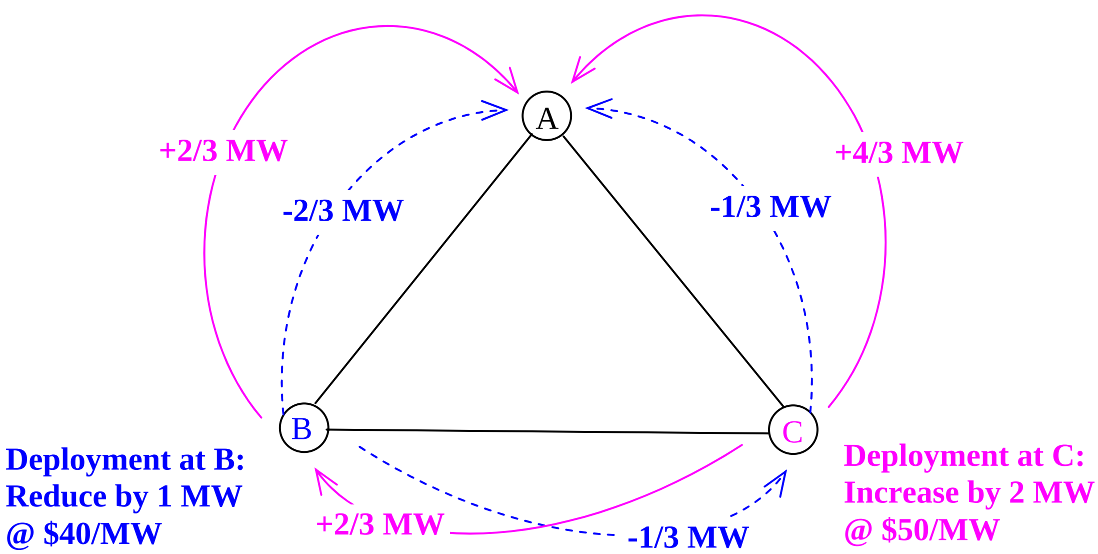

Figure 10

This example shows how MCPE in a zone can exceed the highest bid in that zone. It also demonstrates that MCPE can even exceed the highest bid in the whole system. The phenomenon occurs when no more UBES exists in the affected zone to cover the next MW of demand. When congestion occurs, more than 1 MW of re-dispatch is needed in the other zones to serve the next MW of demand. Thus the re-dispatch cost may exceed the bid price of any particular bid.

As stated in the assumptions of the examples, Resource Plan Constraints, Ramp Rate Constraints and BES Bid Constraints are automatically satisfied, i.e., this paper does not consider them. However, those constraints remain important. ERCOT staff intends to write another white paper to address those constraints separately and in detail.