TECHNICAL BULLETIN

Quantifying the Benefits for Participating in EIM

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Table of Contents

Executive Summary

This paper proposes a systematic way to quantify each EIM region's benefits in terms of increased economic surplus, or cost saving. The EIM benefit is calculated by the dispatch cost difference between the EIM dispatch and a counterfactual without EIM dispatch. If there is energy transfer or flex ramp transfer between EIM regions, the cost of the transfer will be shifted from the supply region to the demand region. The counterfactual without EIM dispatch is obtained by rerunning the same EIM market clearing engine with modifications to mimic the pre EIM dispatch practice. The ISO will quantify the EIM benefits based on the fifteen-minute market, which will capture the majority of benefits. There are additional benefits in the 5-minute market, but the ISO does not plan to calculate the benefits on a 5-minute basis because the without EIM counterfactual "reruns" would consume extensive additional resources and complexity to simulate 288 RTD market runs daily. Calculating the benefits on a 15-minute basis reflects a conservative approach that may undervalue the true benefit. The ISO will conduct some test cases using both 15 minute and 5 minute intervals for the without EIM to estimate the additional 5-minute benefits.

Background

PacifiCorp and the California ISO have agreed to jointly create a real-time energy imbalance market (EIM) by October 2014. Following the October Go-live, EIM will be available to all Balancing Authorities (BA) in the West. The EIM will efficiently dispatch resources across multiple balancing authorities in real time to balance supply and demand, and is expected to reduce system costs, while also enhancing reliability. The EIM utilizes advanced optimization technology to dispatch resources, and encourages flexible resource participation via flexible capability compensation, which helps to accommodate more renewable generation. EIM participants can benefit from (1) more efficient dispatch of resources both within and between balancing authorities, and (2) the ability to share flexible resources to accommodate variable energy resources. A joint PacifiCorp/ISO study performed by the E3 consulting firm predicts EIM will create a benefit ranging from $12 million to $129 million in 2017.[1] Once EIM is implemented, the California will quantify EIM benefits of the participating EIM entities using real market data. This technical paper will outline the methodology that the ISO will use to quantify the EIM benefits.

The benefit of participating in EIM is measured by the economic surplus. Economic surplus, also known as total welfare or market efficiency, is the difference between consumers' willingness to pay and the producers' cost to produce. Economic surplus characterizes the net benefit of producing and consuming electric energy. If demand's willingness to pay is viewed as negative cost, economic surplus is equal to the absolute value of total dispatch cost. So we can also consider the EIM benefit as representing the cost savings. Participating in EIM may increase an EIM region's economic surplus, or save cost, because:

[1] PacifiCorp, Energy Imbalance Markets Summary, http://www.pacificorp.com/content/dam/pacificorp/doc/About_Us/Energy_Imbalance_Market/6709-49_PC_EIM_Handout_8.5x11_r7.pdf

- additional transfers may clear economically between EIM regions, which let lower cost generation from one EIM region to meet demand in another EIM region with higher cost, and also help mitigate regional over generation or under generation risks,
- new participating resource that are not dispatched by the BA may be dispatched in EIM economically, which replaces more expensive generation,
- resources with EIM offers may be re-dispatched to reduce overloads on transmission paths and to reduce cost,
- real-time incremental load will be met economically subject to transmission limitations, and
- EIM may require less flexible ramping per region, and allow flexible ramping transfers between regions, which may reduce the overall procurement cost.

In order to calculate the magnitude of these possible benefits, we need to compare the economic surplus of the actual EIM dispatch with that of a counterfactual dispatch absent the EIM. The counterfactual dispatch without an EIM is obtained by re-clearing the market to meet the same load while respecting the same transmission constraints with the following modifications to mimic the pre EIM dispatch practice.

We will calculate the bid costs associated with the incremental and decremental dispatches between EIM and the without EIM counterfactual, and sum them up to be the total EIM benefit. We will also divide the total benefit into regions, so each BAA has its own calculated regional benefit.

Method

The method here will calculate the benefit of participating EIM for each EIM region, or BAA. The method requires EIM market clearing results, and the counterfactual clearing results from re-simulating the market clearing without EIM.

Counterfactual without EIM dispatch

The counterfactual without EIM dispatch is to mimic the pre EIM dispatch practice, where each BAA meets its own load and flex ramp without relying on real-time transfers or dispatching new participating resources. Specifically, the without EIM dispatch is obtained by rerunning the EIM market clearing engine with the following modifications.

- For all EIM regions:
  - disallow EIM transfers (beyond the base schedule transfers),
  - disallow flex ramp sharing and transfer between regions.
- For all EIM regions except CAISO:
  - fix the dispatch at the base schedule for each new participating resource,
  - if a resource list has been provided by an EIM BA identifying the resources they control and dispatch in real time pre EIM, limit the pool of dispatchable resources based on the provided list,
  - penalize deviations from base schedules by adding penalty cost of deviations to the objective function, so it results in the minimum sum of megawatt changes (absolute

values) in dispatching generation to eliminate overloads within the EIM created by base schedules, and prevents base schedules from clearing against each other.

By making these modifications, the counterfactual without EIM dispatch is expected to produce the following results:

- For all EIM regions:
  - No addition EIM transfers can be cleared.
  - Each region meets its own regional flex ramp requirement.
- For all EIM regions except CAISO:
  - New participating resources stays at the base schedule.
  - Base schedules cannot economically clear against each other.
  - Transmission overloads from base schedules are relieved by the most physically effective resources, not by the most economic resources.
  - Each non CAISO region's incremental real-time load from base schedules is met in economic merit order by supply from the same region that does not overload transmission paths.

These outcomes are consistent with how each BAA dispatch resources in real-time in response to system conditions changes pre EIM.

Energy and flex ramp transfer cost

Because the counterfactual without EIM dispatch maintains each region's independence, the change in the cost of the dispatch in one region will be attributable to meeting the load in the same region. However, that will not be the case in the EIM dispatch because EIM energy transfers and flex ramp transfers may raise cost in one region in order to reduce the cost of meeting load in another region. In this case, we have to shift the transfer cost from the exporting region to the importing region in order to correctly calculate each region's benefit from the EIM dispatch.

The energy transfer cost is the transfer MW times the average market clearing price of the transfer. If we use the convention that import MW is positive, and export MW is negative, then adding the transfer cost to each region will correctly shift cost in or out depending on weather it is import or export. The reason for using the average transfer price is that if the transfer constraint between two EIM regions is binding, the market clearing prices for the transfer are different on the source side and the sink side. In this case, we will use the average market clearing price, i.e. $0.5\left(LMP_{exp}^{EIM} + LMP_{imp}^{EIM}\right)$, to calculate the transfer cost. In doing this, any congestion rent over the tie lines will be split in half between the importing and exporting region. If the transfer constraint between the ISO and PAC is binding, then the transfer between the ISO and PAC has average price

$$0.5(LMP_{CAISO}^{EIM} + LMP_{PAC}^{EIM}) = LMP_{MALIN}^{EIM} + 0.5 \cdot SP_{CAISO-PAC}^{EIM}$$

which is the LMP at MALIN plus half of the shadow price of the transfer between the ISO and PAC. If the transfer constraint between the PACW and PACE is binding, then the transfer between the PACW and PACE has average price

$$0.5(LMP_{PACW}^{EIM} + LMP_{PACE}^{EIM}) = LMP_{HMWY}^{EIM} + 0.5 \cdot SP_{PACW-PACE}^{EIM}$$

which is the LMP at Hemingway plus half of the shadow price of the transfer between the PACW and PACE.

When PAC is exporting energy to CAISO, the total cost for the transfer also includes a Greenhouse Gas (GHG) cost[2]. Absent of intra region congestion, PAC will have two system wide LMPs. One LMP is the marginal cost to meet PAC internal load, and the other LMP is the marginal cost to meet CAISO load via the transfer. The LMP to meet CAISO load via the transfer is $LMP_{MALIN}^{EIM} + SP_{CAISO-PAC}^{EIM}$. The LMP to meet PAC load is $LMP_{MALIN}^{EIM} + SP_{CAISO-PAC}^{EIM} + SP_{CAISO-PAC}^{EIM,GHG}$, where $SP_{CAISO-PAC}^{EIM,GHG}$ is the GHG transfer constraint shadow price. Note that these transfer shadow prices are all less than or equal to zero. The export price for the transfer to do the EIM benefit calculation should be the LMP to meet CAISO load, i.e. $LMP_{MALIN}^{EIM} + SP_{CAISO-PAC}^{EIM}$. This is because the production cost in PAC already includes the GHG cost, and the LMP to meet CAISO also includes the GHG cost, so the difference between them will capture the benefit correctly. Therefore, with the GHG cost model, we will still calculate the ISO and PAC average price the same way, i.e.

$$\begin{aligned} 0.5\left(LMP_{exp}^{EIM} + LMP_{imp}^{EIM}\right) &= 0.5(LMP_{MALIN}^{EIM} + SP_{CAISO-PAC}^{EIM} + LMP_{MALIN}^{EIM}) \\ &= LMP_{MALIN}^{EIM} + 0.5 \cdot SP_{CAISO-PAC}^{EIM} \end{aligned}$$

For flex ramp, we also need to calculate the flex ramp transfer cost. The flex ramp transfer cost is equal to the allocated flex ramp cost minus the flex ramp supply payment in that region. The flex ramp supply market payment is equal to the sum of the flex ramp supply times the flex ramp market clearing price in that region. The allocated flex ramp cost is the flex ramp cost allocation to that region based on the ratio of individual regional requirement. The difference between them is the flex ramp transfer cost evaluated at the market clearing price.

For example, the system wide requirement is 100 MW, and the system wide flex ramp price is $1. So the total flex ramp market payment is $100. Region 1 supplied 70 MW, region 2 supplied 30 MW. The individual regional requirement is 60 MW per region. The $100 total flex ramp market payment is allocated to the two regions equally based on the 60/60 ratio. For region 1, the flex ramp supply payment is $70, and the allocated flex ramp cost is $50. We will add $50–$70 = –$20 to region 1's cost, which means region 1 is an exporting region, and we need to shift $20 out of the region. Similarly, we will add $50–$30 = $20 to region 2, which means region 2 is an importing region, and we need to shift $20 into the region.

In summary, we will add transfer cost to each EIM region, and the transfer cost is calculated as follows:

[2] California ISO, energy imbalance market draft final proposal, https://records.oa.caiso.com/sites/MID/MIP/MDRP/Records/Initiatives/Full%20Network%20Model/2014-09-17_Pre-implementation%20analysis%20to%20Board/FNM_pre-implementation_analysis%20for%20BOG.docx

- for CAISO-PAC energy transfer, the transfer cost is equal to the transfer MW times $LMP_{MALIN}^{EIM} + 0.5 \cdot SP_{CAISO-PAC}^{EIM}$,
- for PACW-PACE energy transfer, the transfer cost is equal to the transfer MW times $LMP_{HMWY}^{EIM} + 0.5 \cdot SP_{PACW-PACE}^{EIM}$,
- for flex ramp transfer, the transfer cost is equal to allocated flex ramp cost minus total flex ramp supply payment in that region.

EIM benefit calculation steps

1. After EIM market clears, take the EIM savecase, create the counterfactual with the modifications for the without EIM case, and rerun the market with the same market clearing engine.
2. Calculate the difference between the EIM dispatch and the counterfactual dispatch, which will be referred as the delta dispatch.
3. Calculate the bid cost associated with the delta dispatch between the actual EIM dispatch and the counterfactual dispatch for each EIM region.
4. Calculate each region's energy transfer cost and flex ramp transfer cost.
5. Combine each region's delta dispatch costs and transfer costs to get the regional benefit.

Example

In this example, we will demonstrate how to apply the method to quantify the EIM benefits. The example is illustrated in Figure 1. The example consists of two EIM regions. Region 1 has only one generator G1. Region 1 represents the ISO. One can think of G1 is the excessive supply after meeting region 1's demand, and the balanced generation and loads in region 1 has been omitted for simplicity reason. Region 1 and region 2 are connected by a tie line A-B with 25 MW transfer capability. Region 2 has three buses and four generators. The three buses in region 2 are connected to each other by three transmission lines. Line D-B and line C-D all have large transfer capability, and will not be binding constraints. Line C-B's real time transfer capability is 50 MW, and it is likely to be a binding constraint. All the internal lines in EIM region 2 have equal impedances. EIM region 2, as a BA, owns G3, G4, and G5. G2 is a new participating resource in EIM region 2, which the BA does not dispatch pre EIM.

EIM region 2 has submitted balanced base schedules before going into real-time. G3, G4 and G5 supply 140 MW in total to meet load D1. Line C-B real time transfer capability is rated at 50 MW, which is over loaded by 10 MW by the base schedules (0*40+2/3*80+1/3*20=60 MW). EIM will correct this transmission overload. The energy bids and base schedules are listed in Table 1.

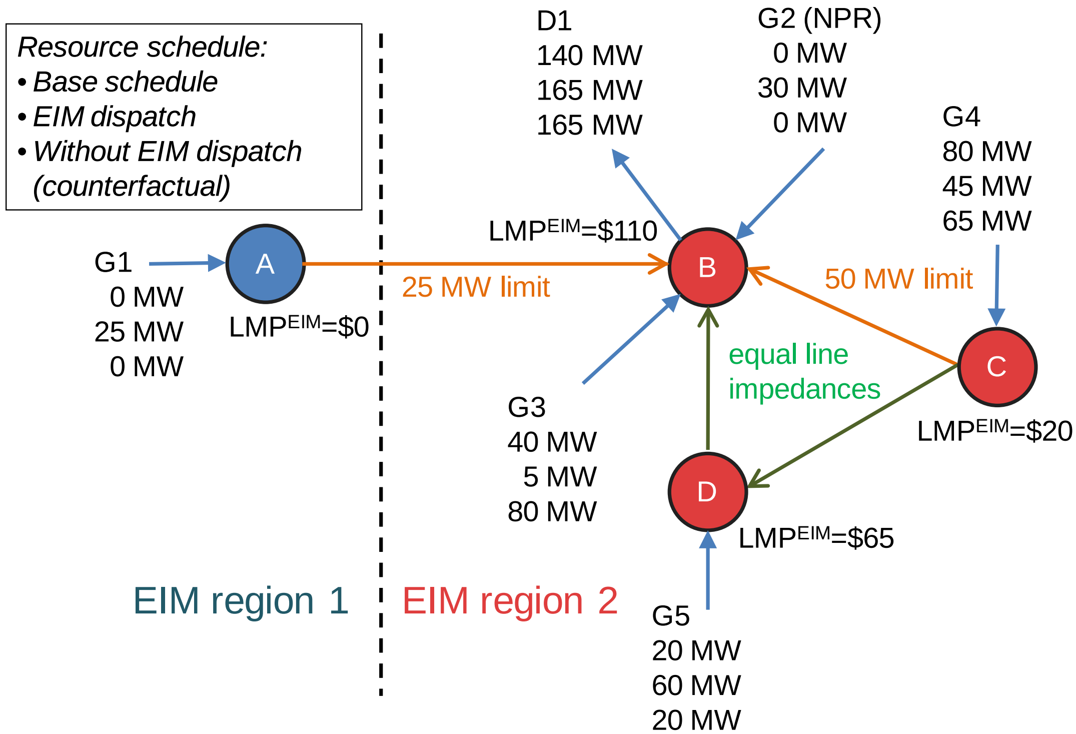

Figure 1: EIM example

One system change in EIM is that load increases by 25 MW from the load base schedule. G1 from region 1 and new participating resource G2 offer more economic supplies into EIM, and will change the market outcome. In addition, region 1 and region 2 each has regional flex requirement of 22 MW. The system wide flex ramp requirement is 40 MW, which is about 10% less the sum of the regional requirements 44 MW. The EIM schedules are listed in Table 1 and the flex ramp awards area listed in Table 2 with the following observations:

- An energy transfer of 25 MW from region 1 to region 2 is cleared, which has been limited by the transfer capability of A-B.
- New participating resource G2 is economically cleared to its Pmax 30 MW.
- Expensive base schedule on G3 is backed down to 5 MW. Had it not been a system wide flex ramp requirement of 40 MW, it should have been further backed down to 0 MW.
- G4 is dec'ed by 35 MW and G5 is inc'ed by 40 MW to relieve the congestion of 10 MW from base schedules, $-2/3*35+1/3*40 = -10$.
- Due to ramp rate limitation, G2, G3, G4 can provide 5 MW flex ramp each. G1 can provide 10 MW flex ramp from its dispatch 25 MW to its Pmax. G5's dispatch has to be withheld to free up capacity to provide the rest 15 MW of flex ramp, which incurs opportunity cost $5/MWh. The opportunity cost sets the system wide flex ramp price to $5/MWh.
- Region 2 supplies 30 MW of the flex ramp, and the 10 MW beyond its allocation 0.5*40=20 MW is a flex ramp transfer to region 1. Therefore, the flex ramp transfer cost from region 2 to region 1 is $50.

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Res.	BAA	Type	Capacity	EIM bid price	Base sched	EIM sched	CF sched	Delta sched	Delta bid cost
G1	1	Gen	35	$0	0	25	0	+25	0
G2	2	NPR	30	$35	0	30	0	+30	1050
G3	2	Gen	90	$110	40	5	80	−75	−8250
G4	2	Gen	80	$20	80	45	65	−20	−400
G5	2	Gen	80	$60	20	60	20	+40	2400
D1	2	Load	N/A	$1000	−140	−165	−165	+0	0

Table 1: EIM and counterfactual without EIM dispatches

Res.	BAA	Type	Ramp capacity	EIM award	EIM price	EIM payment	EIM cost allocation	Transfer cost
G1	1	Gen	35	10	$5	$50	$100	$50
G2	2	NPR	5	0	$5	$0		
G3	2	Gen	5	5	$5	$25	$100	−$50
G4	2	Gen	5	5	$5	$25		
G5	2	Gen	40	20	$5	$100		
Tot.				40	$5	$200	$200	$0

Table 2: EIM flexible ramping awards and cost allocation

The without EIM schedules are obtained by rerunning the market clearing engine with the counterfactual modifications. The results are shown in Figure 1 and Table 1. As expected, the following results are observed:

- EIM transfer from region 1 to region 2 does not clear.
- New participating resource G2 stays at base schedule.
- Transmission overload from base schedules on C-B are relieved by inc'ing G3 by 15 MW and dec'ing G4 by 15 MW, which relieves 10 MW of overloads with 2/3 effectiveness. One can verify the other dispatches are less effective. Inc'ing G5 and dec'ing G3 has 1/3 effectiveness. Inc'ing G5 and dec'ing G4 also has 1/3 effectiveness.

- Region 2's incremental 25 MW load is met by G3 as it is the only resource to inc without further overloading C-B.
- Each region has a flex ramp requirement of 22 MW. G1 has 35 MW flex ramp supply, so flex ramp is not binding in region 1. In region 2, G3 and G4 have 5 MW flex ramp supply each, and G5 has 40 MW flex ramp supply, so the flex ramp is not binding in region 2 either.

Now we can calculate each region's EIM benefit. The EIM benefit for region 1 is calculated in Table 3, where we have calculated the energy transfer cost of the –25 MW transfer at average transfer price \$55/MWh. The average transfer price is the average LMP of LMP_A=\$0 and LMP_B=\$110 in EIM. We have also calculated a flex ramp transfer cost \$50, which is the cost of flex ramp incurred in region 2 to meet region 1's allocation. The regional benefit for region 1 is cost saving of \$1325. As a convention, negative benefit number represents a cost saving in the table.

The EIM benefit for region 2 is calculated in Table 4, where we have added a 25 MW of importing energy transfer at cost \$55/MWh. We have also calculated a flex ramp transfer cost –\$50, which is to shift out the cost of flex ramp incurred in region 2 to meet region 1's requirement. The regional benefit for region 2 is cost saving of \$3875. The total system EIM benefit is 1375+3825 = \$5200.

The congestion rent on A-B is 110*25 = 2750. We can see half of it goes to region 1's benefit as the transfer cost, so the othe half stays in region 2.

Res.	BAA	Type	EIM bid price	EIM sched	CF sched	Delta sched	Delta bid cost
G1	1	Gen	\$0	25	0	+25	0
ET-exp	1	En Transfer	\$55	–25	0	–25	–1375
RT-imp	1	Flex ramp Transfer					50
Total	1	BAA		0	0	0	–1325

Table 3: EIM benefit for region 1

Res.	BAA	Type	EIM bid price	EIM sched	CF sched	Delta sched	Delta bid cost
G2	2	NPR	$35	30	0	+30	1050
G3	2	Gen	$110	5	80	–75	–8250
G4	2	Gen	$20	45	65	–20	–400
G5	2	Gen	$60	60	20	+40	2400
D1	2	Load	$1000	–165	–165	0	0
ET-imp	2	En transfer	$55	25	0	+25	1375
RT-exp	2	Flex ramp Transfer					–50
Total	2	BAA		0	0	0	-3875

Table 4: EIM benefit for region 2