PJM-MISO
Interchange Optimization & Interface Pricing

MISO Seams Management Working Group

October 28, 2013

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Issue Background

- The MISO-PJM JCM Forum has considered steps to improve both the efficiency of MISO/PJM Interchange & the Interface Prices that the RTOs use to settle interchange transactions
- I have offered criticism of the RTOs' Interface Prices at a number of JCM meetings
- This presentation is to share a detailed critique

MISO-PJM Interchange

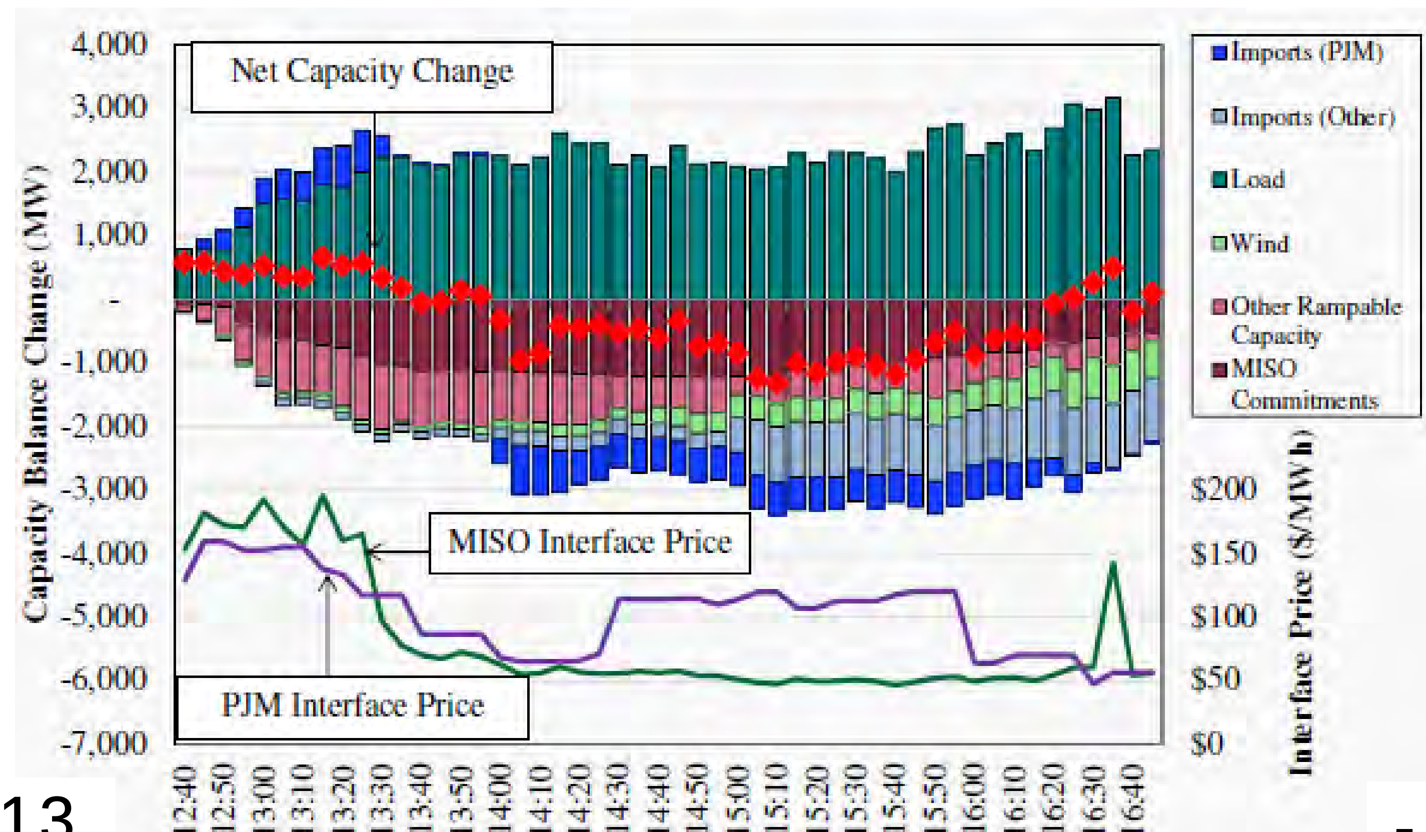
- The MISO and PJM Markets accommodate Interchange Transactions across the interface
- Each Transaction is scheduled by a Market Participant, & is scheduled in both Markets
- Exports are Charged, and Imports are Credited
- MISO and PJM each calculate an Interface Price used to settle these Transactions
- The Difference between MISO's ***PJMC*** price and PJM's ***MISO*** price is the net payment to interchange transactions

Efficient Interchange – Benefits and Obstacles

- The ability to transfer power between regions makes possible lower aggregate production costs
- Achieving efficient interchange between MISO and PJM, however, faces a number of obstacles:
  - Market Participants must schedule transactions in both regions in anticipation of future price differences
  - No coordination guards against overshoot or undershoot
  - Unpredictable uplift charges deter participation

Interchange is Often Inefficient

- MISO's IMM has pointed out that MISO/PJM Interchange is often highly inefficient, with price uncertainty and scheduling lags causing schedules to flow contrary to price signals
- See 2012 SOTM & (at right) 20131001 IMM Quarterly Report to MSC, showing July 17, 2013



https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=160510

Improving Efficiency of Third-Party Scheduling

- Scheduling Alignment in Progress
  - MISO filed changes in ER13-2233 on August 23 that would reduce scheduling notification lead time to align with PJM
  - PJM plans to seek stakeholder approval to match MISO scheduling timeline if FERC approves MISO's proposal
- Interchange Optimization Proposed
  - This is a Recommendation from MISO's IMM
  - Current JCM timeline has tariff filings at end of 2014
  - Note: PJM Members vote on Coordinated Transaction Scheduling with NYISO – scheduled for October 24

Key Role of Correct Interface Prices

- Addressing uncertainty and lack of coordination that now impedes efficient scheduling, however, **will not lead to optimal interchange if the Interface Prices are not correct**
- The MISO[1] & PJM[2] IMMs have identified flaws in the RTOs' pricing of non-adjacent interfaces, focusing on PJM's Interface Price for Ontario
- These critiques to not go far enough, however: MISO's ***PJMC*** price and PJM's ***MISO*** price are not the economically correct prices either

1. http://www.potomaceconomics.com/uploads/reports/2012_SOM_Report_final_6-10-13.pdf @ p. 70/101
2. http://www.monitoringanalytics.com/reports/Presentations/2013/IMM_MIC_Scheduling_Issues_20131001.pdf

Characteristics of Proper Interchange Prices

- Interface Prices Should be set at Marginal Cost of adjusting dispatch to accommodate interchange
  - This is the same Marginal-Cost Pricing principle that governs calculation of Nodal LMPs
  - Region that charges Exports less, or pays Imports more, than this incremental cost is losing money at the Margin

Important: This Marginal Cost depends on allocation of costs of congestion caused by incremental Interchange

- Optimal 2-Region Interchange occurs when both regions have the same incremental interchange cost, since no savings result from further transfers

Regions' Interface Prices Should Converge at Optimal Dispatch

- Prices that do not converge at the least-cost dispatch will provide an incentive to schedule additional interchange that will move the joint dispatch away from the optimum
- Even if the RTOs could somehow move to the optimal dispatch, and remain there, in spite of price signals to move away from the optimum:
  - they would have to determine which among schedules with equivalent offers should be approved, and
  - RTOs would be making non-zero payments to schedules having zero marginal value, with adverse impacts on congestion funds and (possibly) FTR funding

Current Interface Prices

PJM tariff, at 2.6A of Attachment K, describes multiple Interface Price methodologies for various interfaces

- PJM's ***MISO*** price is simple average of 9 MISO-bus LMPs as calculated in PJM's SCED*
  - http://www.miso-pjm.com/~/media/committees-groups/stakeholder-meetings/pjm-miso-joint-common/20130321/20130321-item-06-pjm-interface-pricing.ashx

MISO describes Interface Price calculations at 5.1 of *BPM for Energy and Operating Reserve Markets*

- MISO's ***PJMC*** price is average MISO-SCED LMP of all PJM generators in MISO's model
- MISO is contemplating a revised, Nine-PJM-bus definition, using a methodology similar to PJM's
  - http://www.miso-pjm.com/~/media/committees-groups/stakeholder-meetings/pjm-miso-joint-common/20130920/20130920-item-05-miso-presentation-interface-pricing.ashx

*SCED is acronym for Security-Constrained Economic Dispatch

Congestion-Cost Allocation and Interface Prices

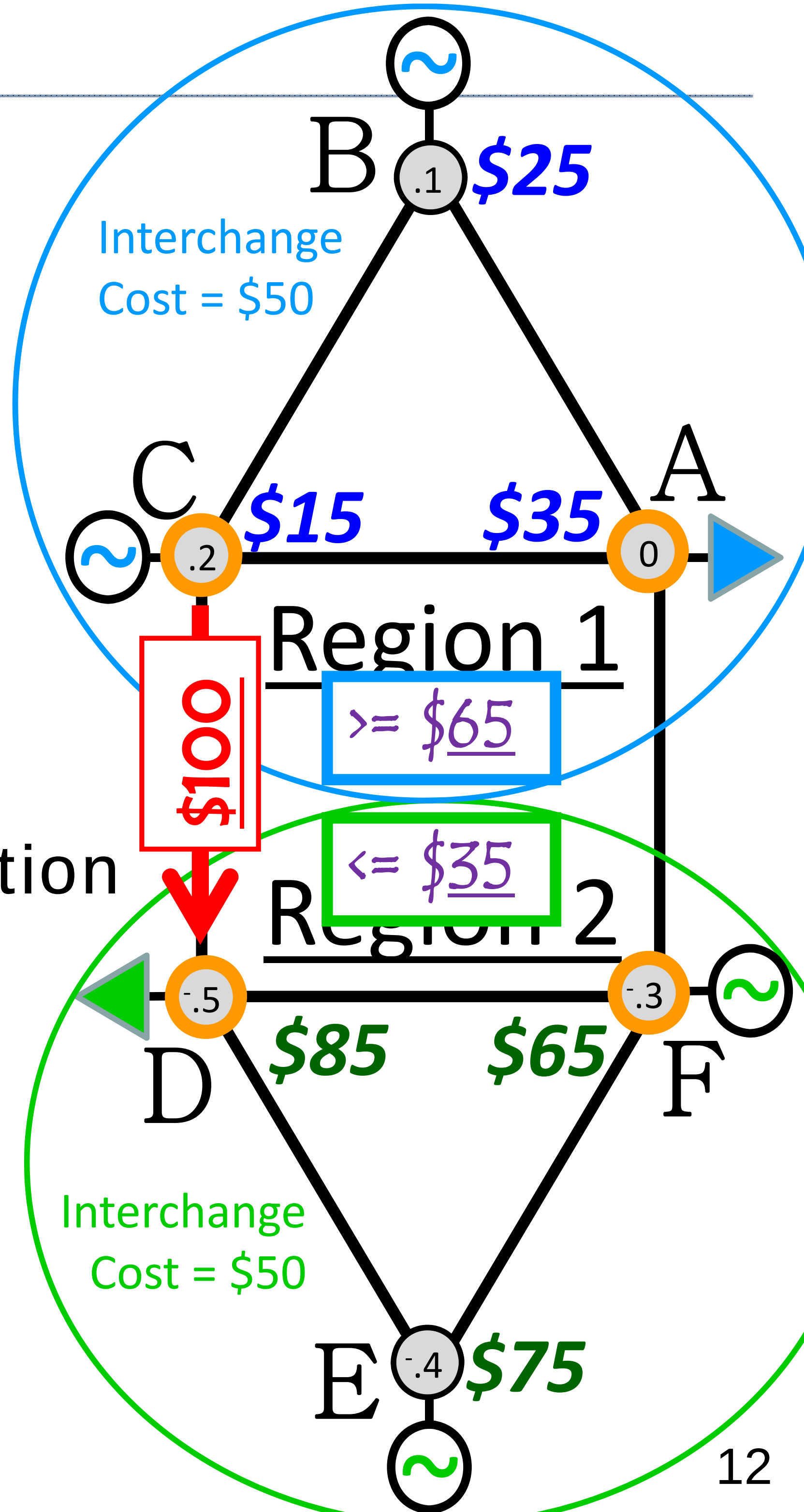
- By selecting only <u>*External*</u> pricing nodes for the Interface Price definition, both RTOs appear to assume that the RTO doing the calculation will be responsible for full cost of seams congestion resulting from incremental interchange
- This may have been reasonable at an early stage of inter-regional coordination, but not with JOA & M2M in place

As a consequence of this assumption, existing Interface Prices:

1. will <u>*not*</u> tend to reflect actual Interchange Marginal Cost, which depends on the actual cost allocation specified for coordinated congestion management
2. will <u>*not*</u> tend to converge at optimal joint dispatch, but instead will tend to differ by an amount related to the shadow price of binding constraints

Correct Interface Price Calculation

- Appendix accompanying this presentation shows calculation of efficient Interface Prices for a simplified 2-region network
- It shows that, once RTOs jointly specify cost allocation for congestion due to incremental interchange:
  - Efficient interface prices that converge at optimal dispatch exist and can be calculated
  - The RTOs' current methodology cannot produce the correct prices in a simple general case



Economically Efficient Interface Prices

- Current MISO/PJM approach to Interface Prices — (*fixed) weighted average of nodal LMPs* — will yield prices that converge at the Joint Optimal Dispatch **only if both RTOs use same Nodes and Weights**
- Adoption of *revised* MISO-PJM Interface Prices that use common Nodes and Node Weightings would provide economically efficient price signals
- This common Interface Price definition would also implicitly specify constraint-relief obligations for congestion caused by incremental Interchange and, provided M2M assumptions are aligned, compensate RTOs for marginal cost of supporting Interchange

Additional Issues

1. Direct Inter-RTO Scheduling
2. Day-Ahead Market
3. Non-RCF Constraints
4. Coordination Across Multiple Regions
5. PJM Long-Term FTRs

1. Direct Inter-RTO Scheduling

- In Principle, RTOs could determine & implement optimal interchange directly, without complication of relying on third-party schedules
- Analogous to M2M Process, and could be implemented as a straightforward extension of the existing M2M Process
- RTOs would retain surplus when Interface Prices are not equal, rather than paying third parties for schedules RTOs could implement for free
- PJM has rejected this as inappropriate RTO activity
  - This view is difficult to understand in the context of centrally optimized markets

2. Day-Ahead Market

- Finding optimal Interchange direction, & Scheduling appropriate Transactions, is straightforward in RT, because both RTOs can share information on Binding Constraints and Interface Prices
- This is more difficult in DA, as data from the other RTO is not readily available, and Binding Constraints and Shadow Prices are not coordinated
- Note that similar issue arises in M2M process, to which MISO recently proposed a remedy, which might also be used to coordinate DA Interchange See https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=160496

3. Non-RCF Constraints

- Interchange Shadow Prices converge at optimal interchange if both RTOs' SCEDs are binding on same set of constraints, with same shadow prices
- Reciprocal Coordinated Flowgates bind in Real-Time in both Regions, but other constraints may not
  - Differences in Binding Constraints may complicate Price Convergence at Interchange Optimum
- For this reason, any re-defined Interface should include nodes selected to be relatively insensitive to non-RCF constraints, i.e. close to the seam

4. Coordination Across Multiple Regions

- MISO and PJM IMMs have identified problems with settlement of transactions across multiple regions
- Important to consider alignment of Interface Prices across multiple regions, to avoid opportunities for strategic scheduling that would earn payments in excess of the value of the schedules
- In addressing MISO/PJM Interface Prices, MISO should also consider the SPP & ONT Interfaces, and PJM should also consider the NYISO Interface, so as to avoid unintended consequences

5. PJM Long-Term FTRs

- MISO awards FTRs up to 1 year in advance
- PJM awards some FTRs up to 3.5 years in advance
  - Awarded FTRs are outstanding farther into the future
  - Also, FTRs from multiple annual processes are simultaneously outstanding in PJM
- This may complicate timely modification of PJM's ***MISO*** node definition
  - Note that MW quantities appear to be small for out-year PJM FTRs involving this ***MISO*** node

Conclusions

1. The Interface Prices used by MISO and PJM are not designed to ensure that the RTOs recover the cost of interchange at the margin, or to jointly provide price signals for efficient interchange
2. Defining Interface Prices based on a common set of nodes would provide efficient Interchange price signals, and would ensure proper compensation (consistent with allocation of constraint-relief responsibility implicit in Interface definition)
3. Direct RTO coordination of interchange, with compensation based on Interchange Shadow Prices, as an extension of M2M, would be most efficient and least expensive for Load

- Questions or Comments?

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Optimal Interchange and Interface Pricing

Simplified-Network Examples

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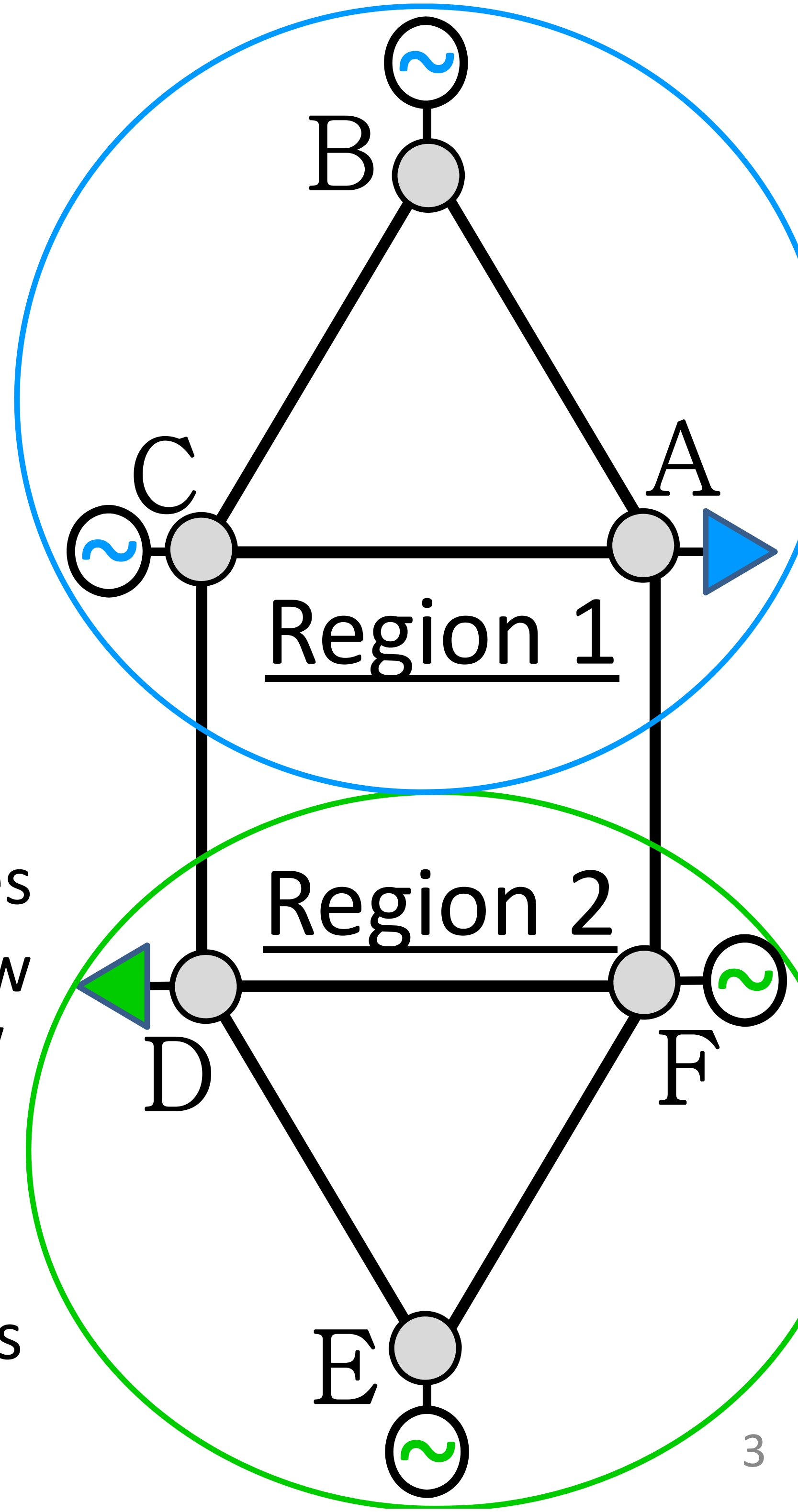
Electricity Market Fundamentals

- MISO and PJM rely on Marginal-Cost Pricing (MCP) in most aspects of their Markets because this is generally the most efficient approach:
  - Leads to lowest production cost
  - Produces dispatch instructions consistent with incentives
  - Reduces opportunities for strategic bidding
- Stakeholders generally understand that deviation from MCP can lead to problems with efficiency and market management
- This Appendix shows that MISO and PJM deviate from MCP in settlement of interchange transactions, and illustrates the many problems that result

6-Bus System

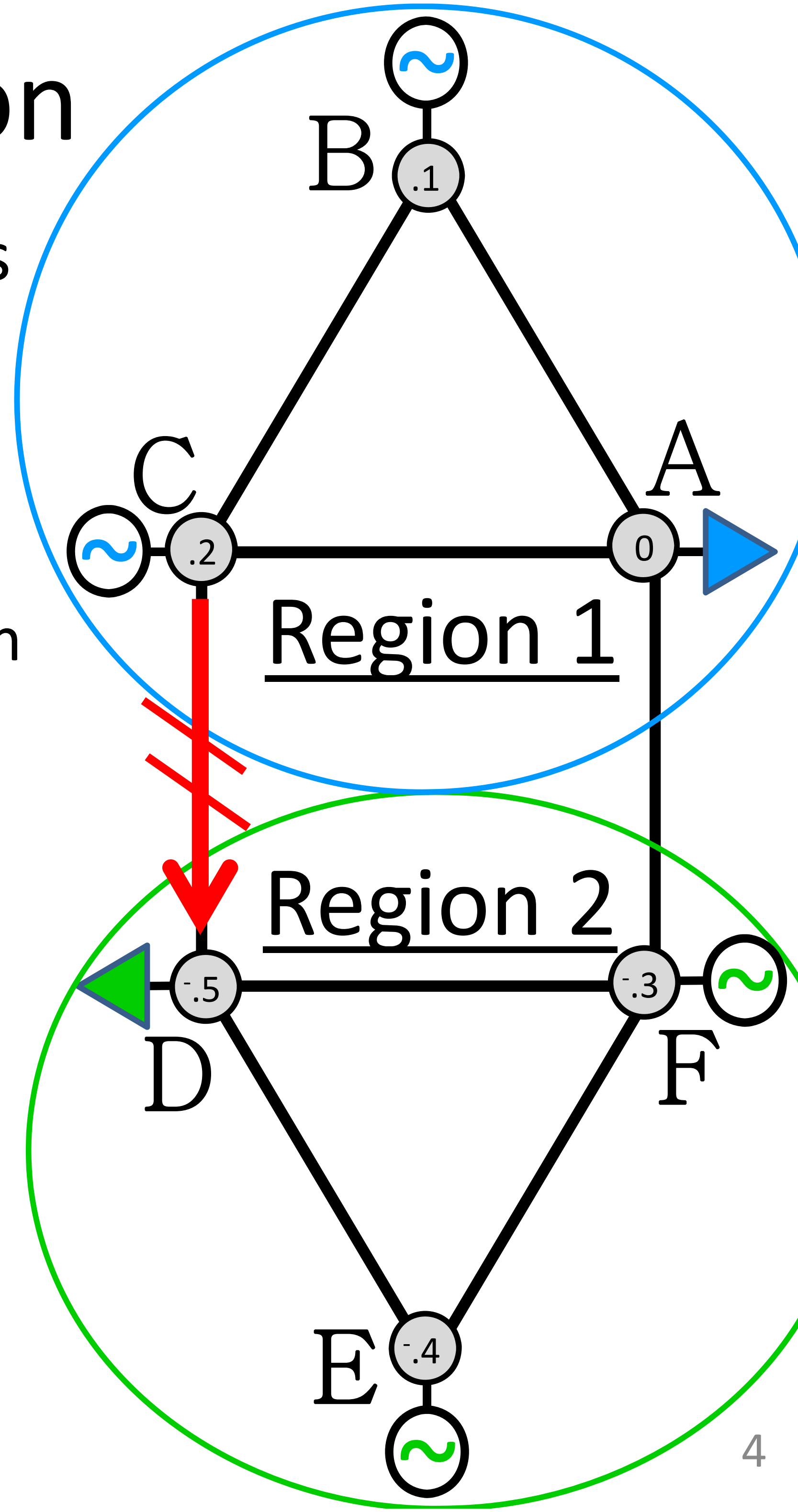
- 2 Regions
  - 2 Generators (with offers) and 1 Load (fixed) in each Region
- 8 Branches
  - Lossless
  - All Impedances Equal
- Branch-Flow Constraints
  - Neglect line-outage Contingencies
  - Each Region limits its Market Flow over each branch to its Firm Flow Entitlement (FFE)
  - Regions Coordinate Congestion Relief, similar to MISO/PJM Market-to-Market (M2M) process



Dispatch in each Region

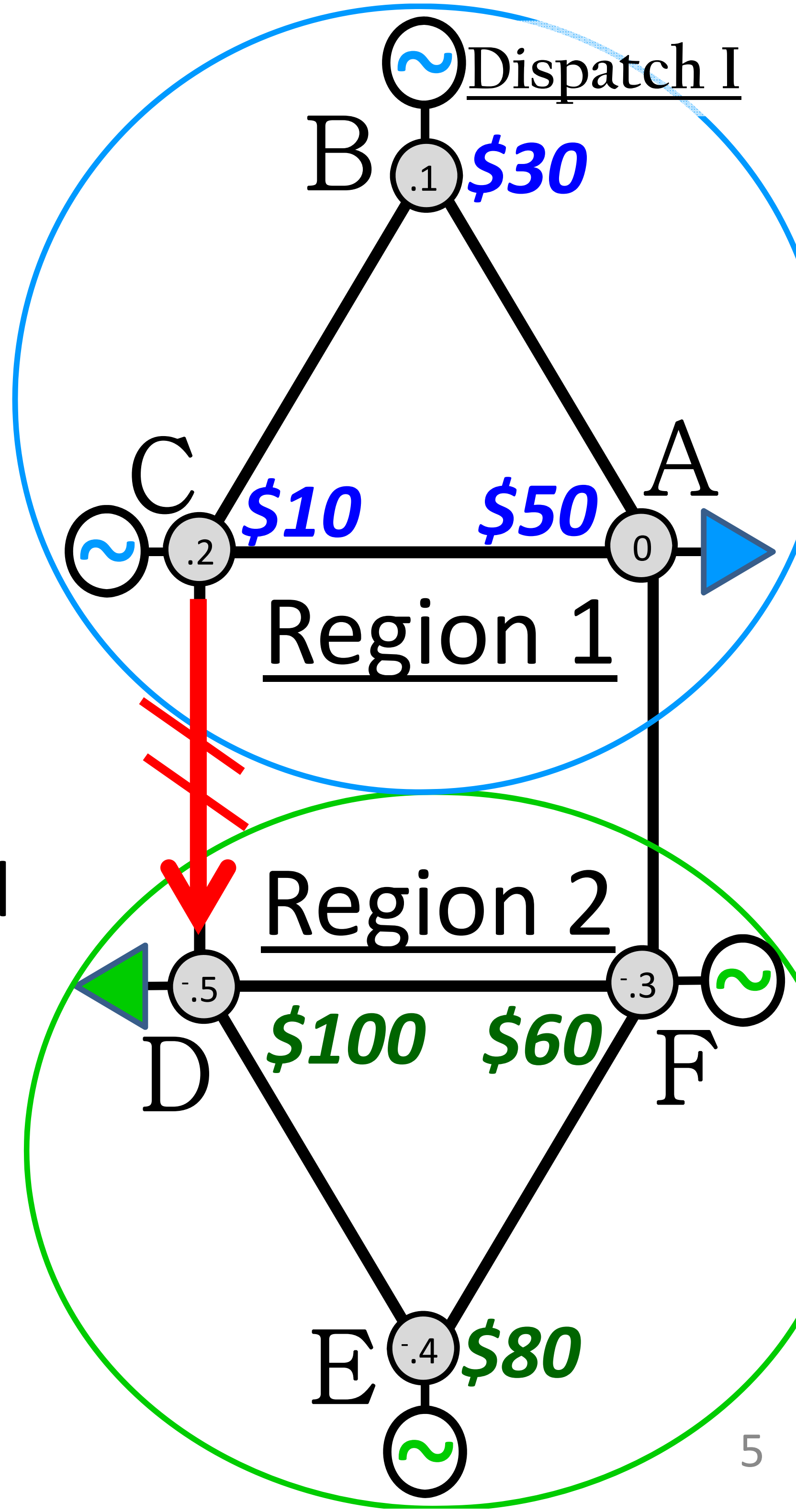
- Accommodate Inter-area schedules
- Economic Dispatch in each Region
- Consider Branch-Flow Constraints
  - System-Intact Constraints Only
  - C→D Binds in each Region's Dispatch
  - Distribution Factors (DFs) as shown:

Region	Bus	Bus Type	Injection D.F. on Branch C--->D (Bus A Reference)
1 (Blue)	A	Load	0
1 (Blue)	B	Gen	0.1
1 (Blue)	C	Gen	0.2
2 (Green)	D	Load	-0.5
2 (Green)	E	Gen	-0.4
2 (Green)	F	Gen	-0.3



Initial Dispatch

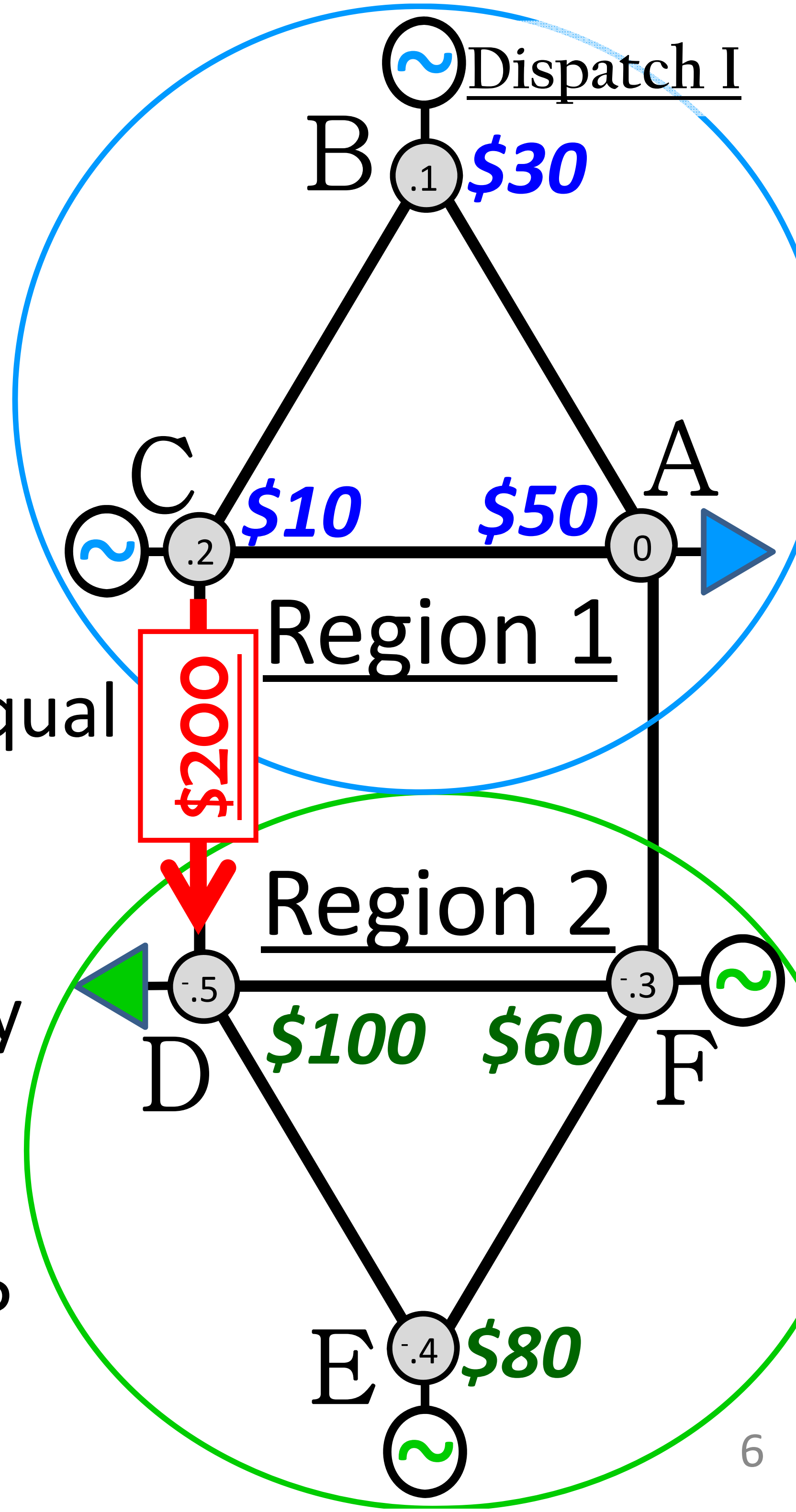
- One possible Dispatch Solution, with each Region's LMPs as shown
- Note that there is no need to specify MW quantities — we could readily find Loads, (increasing) Generator Offers & FFEs to produce situation depicted
- LMPs are Consistent within each Region since LMP differences are proportional to DF differences on the single Binding Constraint…



Dispatch Solution

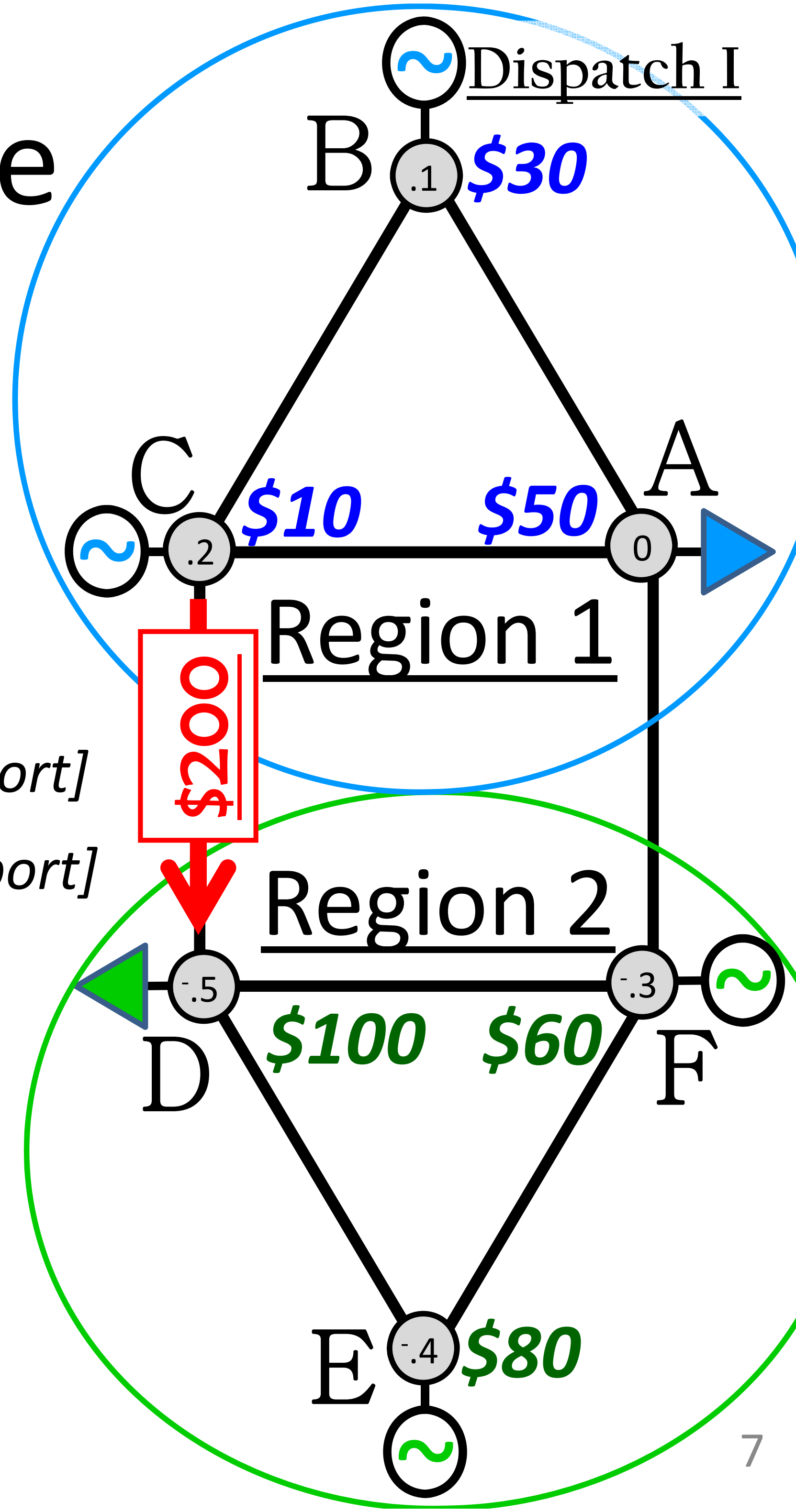
$$LMP_A - LMP_B = \lambda_1 \times (DF_A - DF_B)$$
$$LMP_B - LMP_C = \lambda_1 \times (DF_B - DF_C)$$
$$LMP_D - LMP_E = \lambda_2 \times (DF_D - DF_E)$$
$$LMP_E - LMP_F = \lambda_2 \times (DF_E - DF_F)$$

- $\lambda_1 = \lambda_2 = -\$200$; Shadow Prices Equal
  - Dispatch is Efficient in terms of M2M Constraint Management
- Each Region's LMPs are internally consistent, and Each Dispatch is optimal, provided that each Generator's Marginal Cost = LMP



Consider Interchange

- How can we Increase Interchange from Region 1 to Region 2 by 1 MW while holding C→D Flow constant?
- Adjust B, C, E & F Dispatch subject to the following conditions:
  1) $\Delta_B + \Delta_C = 1$ *[Region 1 Incremental Export]*
  2) $\Delta_E + \Delta_F = {}^{-}1$ *[Region 2 Incremental Import]*
  3) $.1\times\Delta_B + .2\times\Delta_C - .4\times\Delta_E - .3\times\Delta_F = 0$
     [C→D Flow Limit Respected]
- With 4 Variables and 3 Constraints, there are, in principle, multiple possible Redispatch Combinations



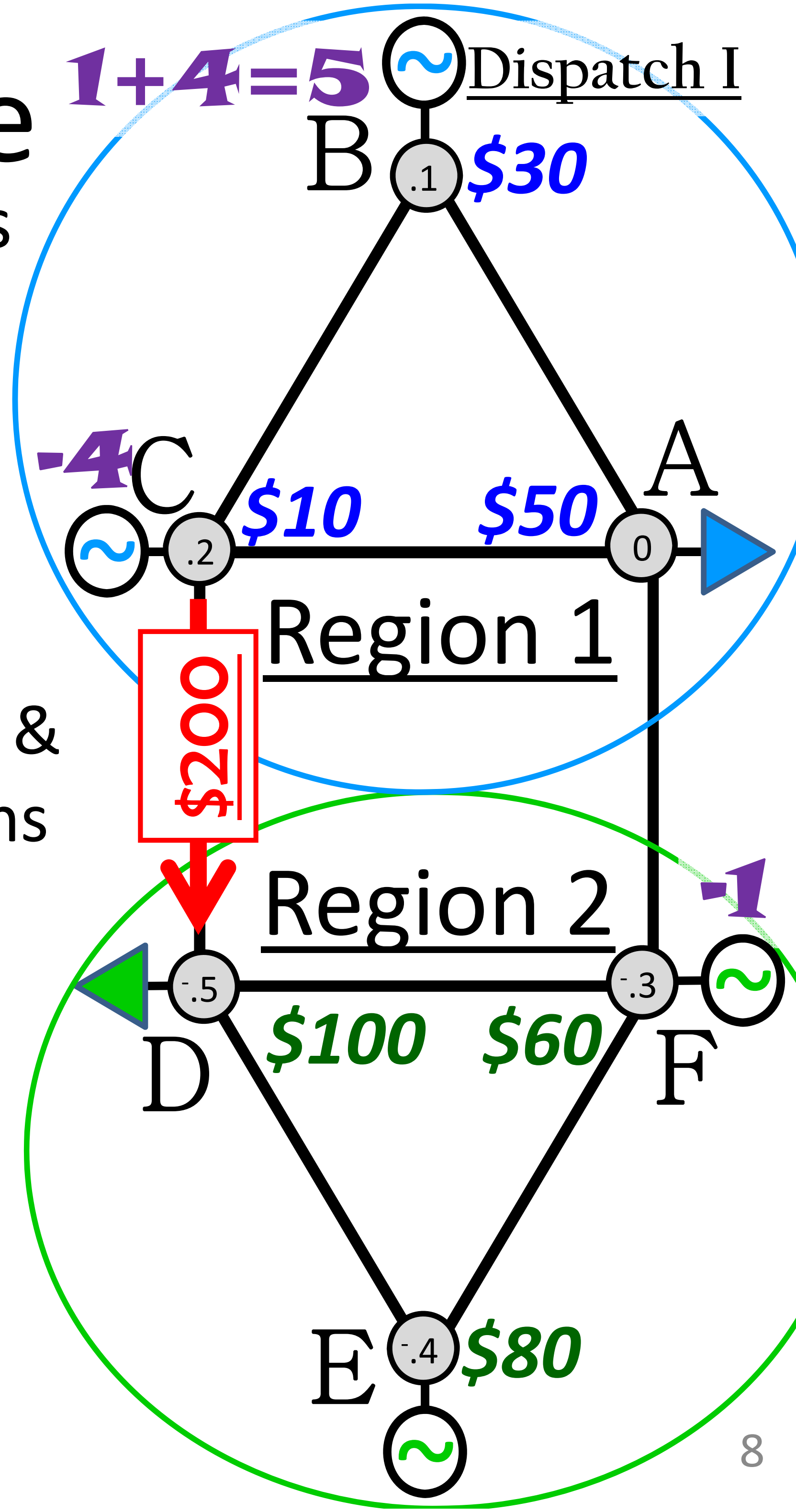
Interchange Increase

Interchange-Increasing Combinations (via inter-Regional coordination)

are Straightforward to derive:

1. Choose any R1 Generator to Inc & any Region-2 Generator to Dec
2. Determine Step-1 constraint impact & Apportion constraint relief to Regions
3. Equal & Opposite changes for the 2 Generators in each Region to satisfy constraint-relief obligation

For Example: Inc B & Dec F by 1 MW; Increases C→D flow by .1– ⁻.3 = .4 MW; Offset via 4 MW Inc at B & Dec at C



All Combinations have Equal Cost

- Valid Redispatch Combinations differ in allocation of costs between Regions, but sum of 2 Regions' Marginal Costs (last row of table) does not change
- *<u>Sum</u>* of *<u>R1-to-R2 Interchange</u>* Costs is same as the *<u>Difference</u>* between the 2 Regions' *<u>Export</u>* Costs (and Both go to Zero at Optimal Interchange)

Incremental Generation	LMP ($/MWh)	Redispatch Combinations for 1MW Incremental R1-to-R2 Interchange (MW)				
ΔB	$30	5	4	3	2	1
ΔC	$10	-4	-3	-2	-1	0
ΔE	$80	0	1	2	3	4
ΔF	$60	-1	-2	-3	-4	-5
Condition Check		(Three Constraints from Slide 7)				
1	ΔB + ΔC	1	1	1	1	1
2	ΔE + ΔF	-1	-1	-1	-1	-1
3	.1ΔB + .2ΔC - .4ΔE - .3ΔF	0	0	0	0	0
Interchange Marginal Cost ($/MWh)						
Region 1	$30×ΔB + $10×ΔC	$110	$90	$70	$50	$30
Region 2	$80×ΔE + $60×ΔF	-$60	-$40	-$20	$0	$20
Total		**$50**	**$50**	**$50**	**$50**	**$50**

Interchange Cost

Take Middle case from previous Table

- Inc Gen B and Dec Gen F by 3 MW
- Inc Gen E and Dec Gen C by 2 MW
- Region 1 Cost = $3 \times LMP_B - 2 \times LMP_C$

  $3 \times (\$30) - 2 \times (\$10) = \$70$

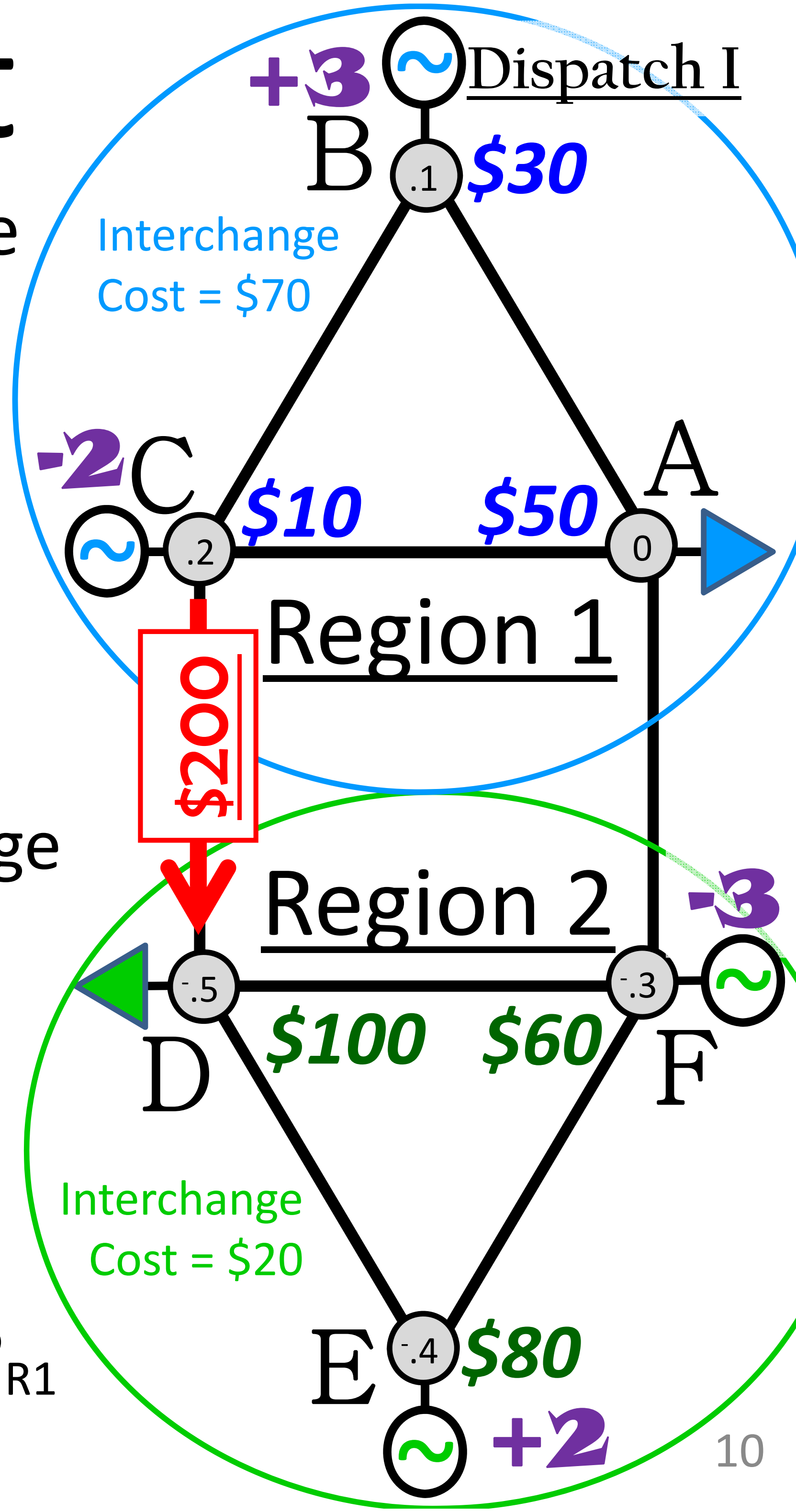
Reverse Redispatch directions to find Incremental Cost of R2➔R1 Interchange

- Region 2 Cost = $3 \times LMP_F - 2 \times LMP_E$

  $3 \times (\$60) - 2 \times (\$80) = \$20$

Thus we can reduce Total Dispatch Cost by Increasing Exports from R2 into R1

- Counterintuitive, since $LMP_{R2} > LMP_{R1}$



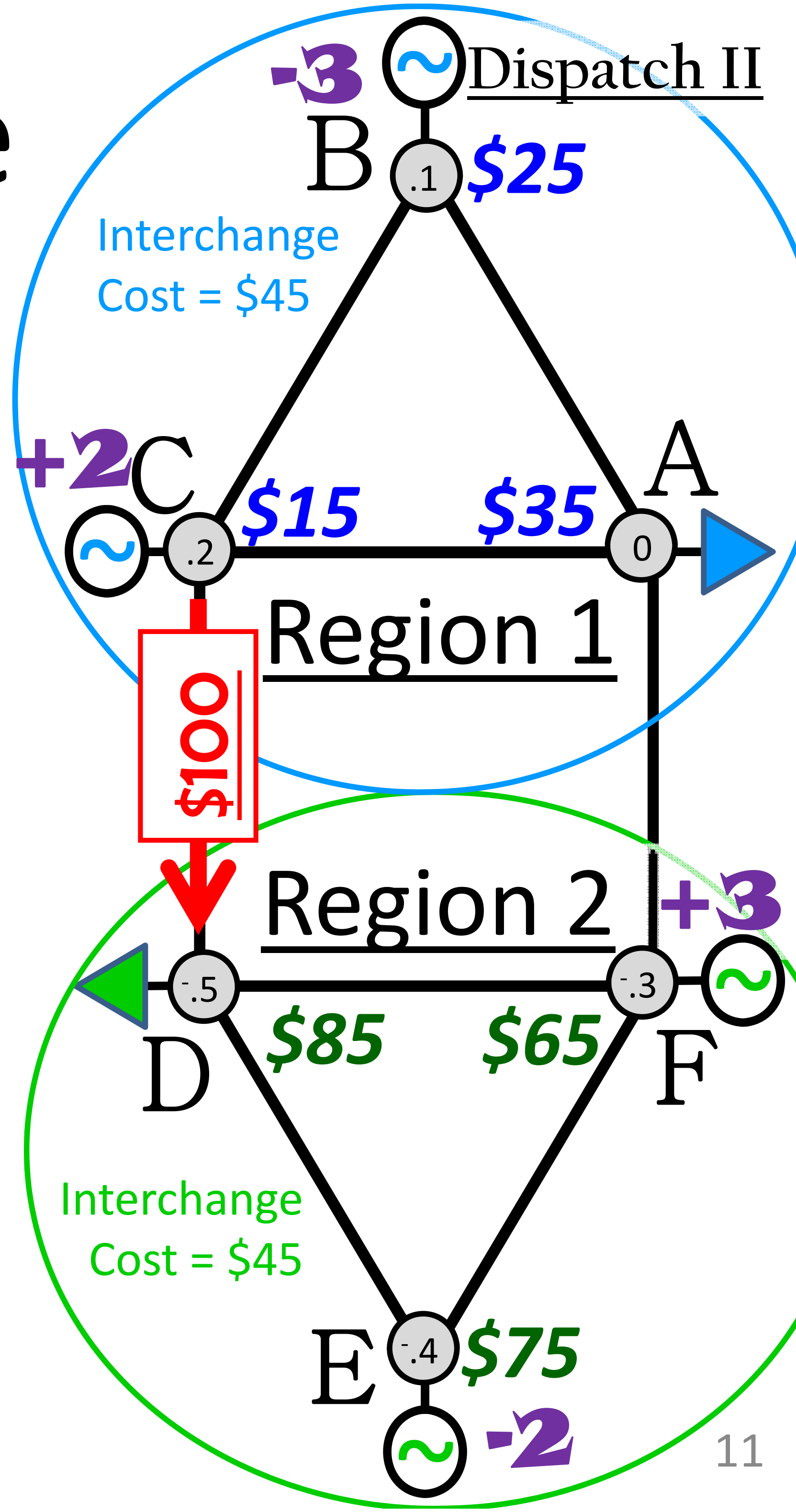
Adjust Interchange

- Increase R2-to-R1 Interchange by adjusting Dispatch of B, C, E & F in proportion to ⁻3, 2, ⁻2 & 3
- Redispatch causes LMPs to change, leading to new Interchange Costs:
- Region 1 Cost = $3 \times LMP_B - 2 \times LMP_C$

  $3 \times (\$25) - 2 \times (\$15) = \$45$
- Region 2 Cost = $3 \times LMP_F - 2 \times LMP_E$

  $3 \times (\$65) - 2 \times (\$75) = \$45$
- Interchange Shadow Prices Equal
  - Interchange is Optimal

(Note that, for both Regions, the Constraint Shadow Price has changed from $200 to $100)



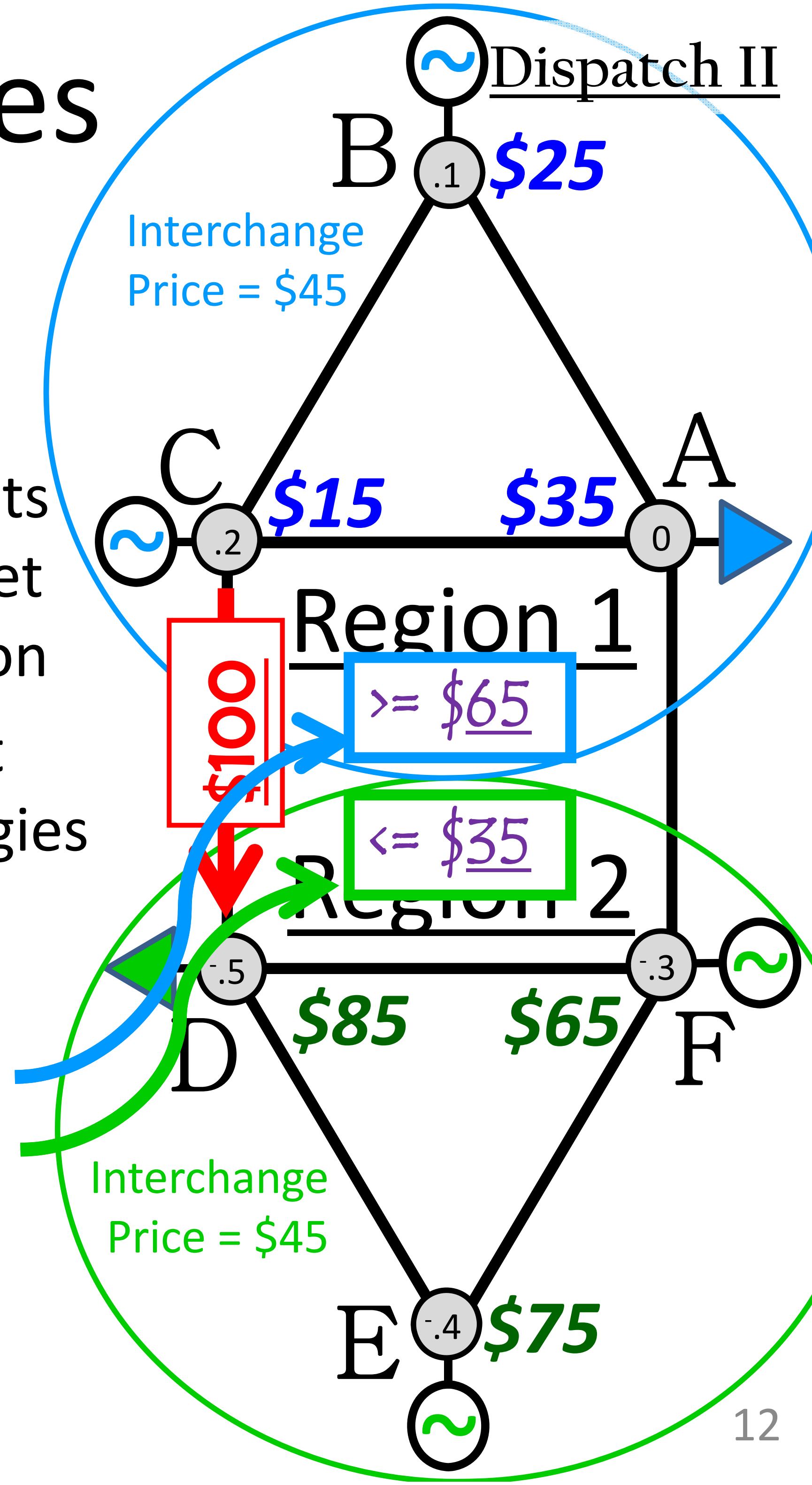
RTOs' Interface Prices

at Optimal Interchange

- At this Optimal 2-Region Dispatch, each Region's Security-Constrained Economic Dispatch (SCED) – using only its own Gen Offers – calculates the same set of 6 nodal LMPs as does the other Region
- This makes it simple to simulate current MISO & PJM Interface Price methodologies
  - weighted average of Other-Region LMPs
  - For any weights (>=0):

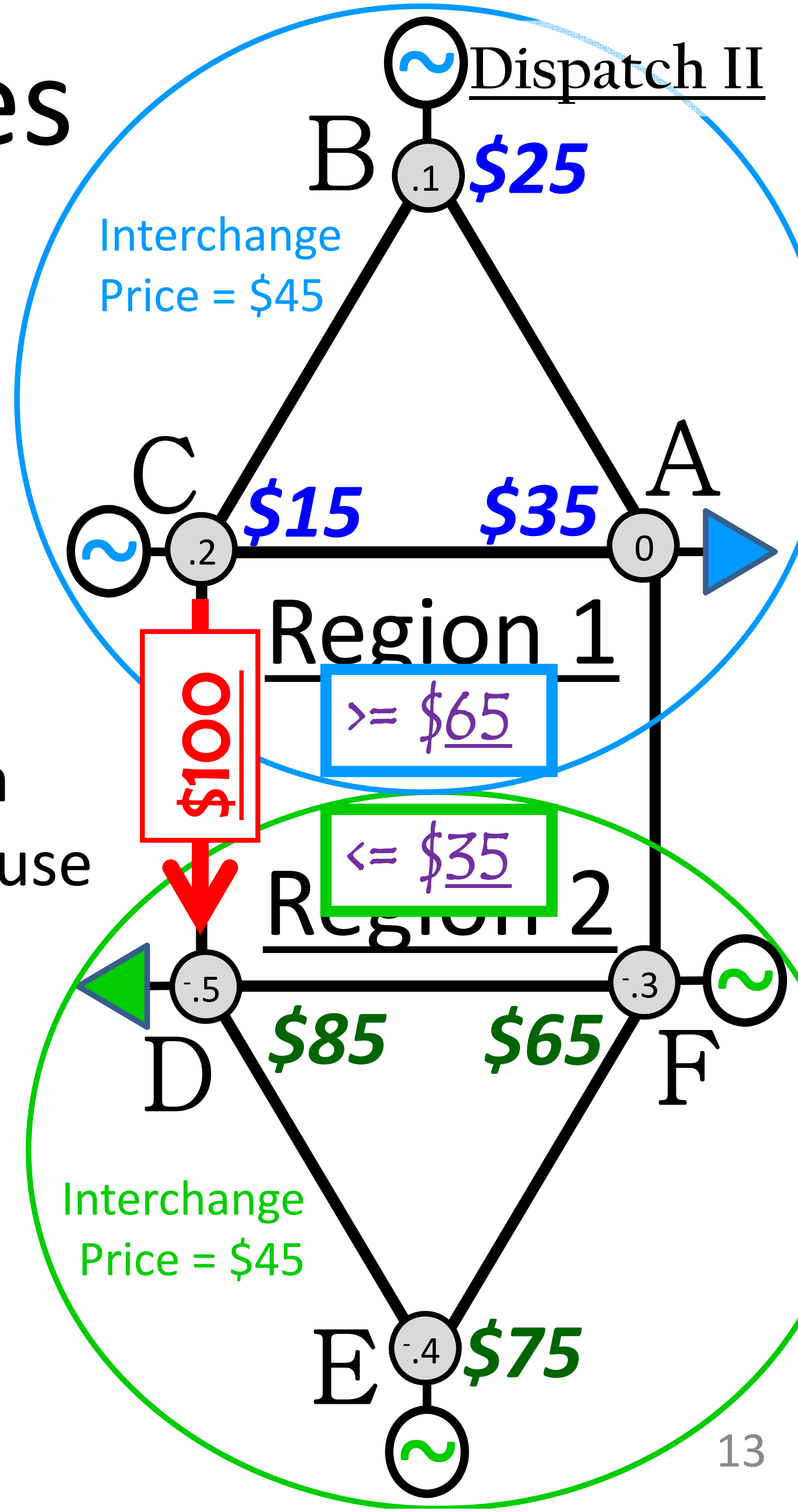
    Region 1 calculates Interface Price >= $65

    Region 2 calculates Interface Price <= $35



RTOs' Interface Prices at Optimal Interchange

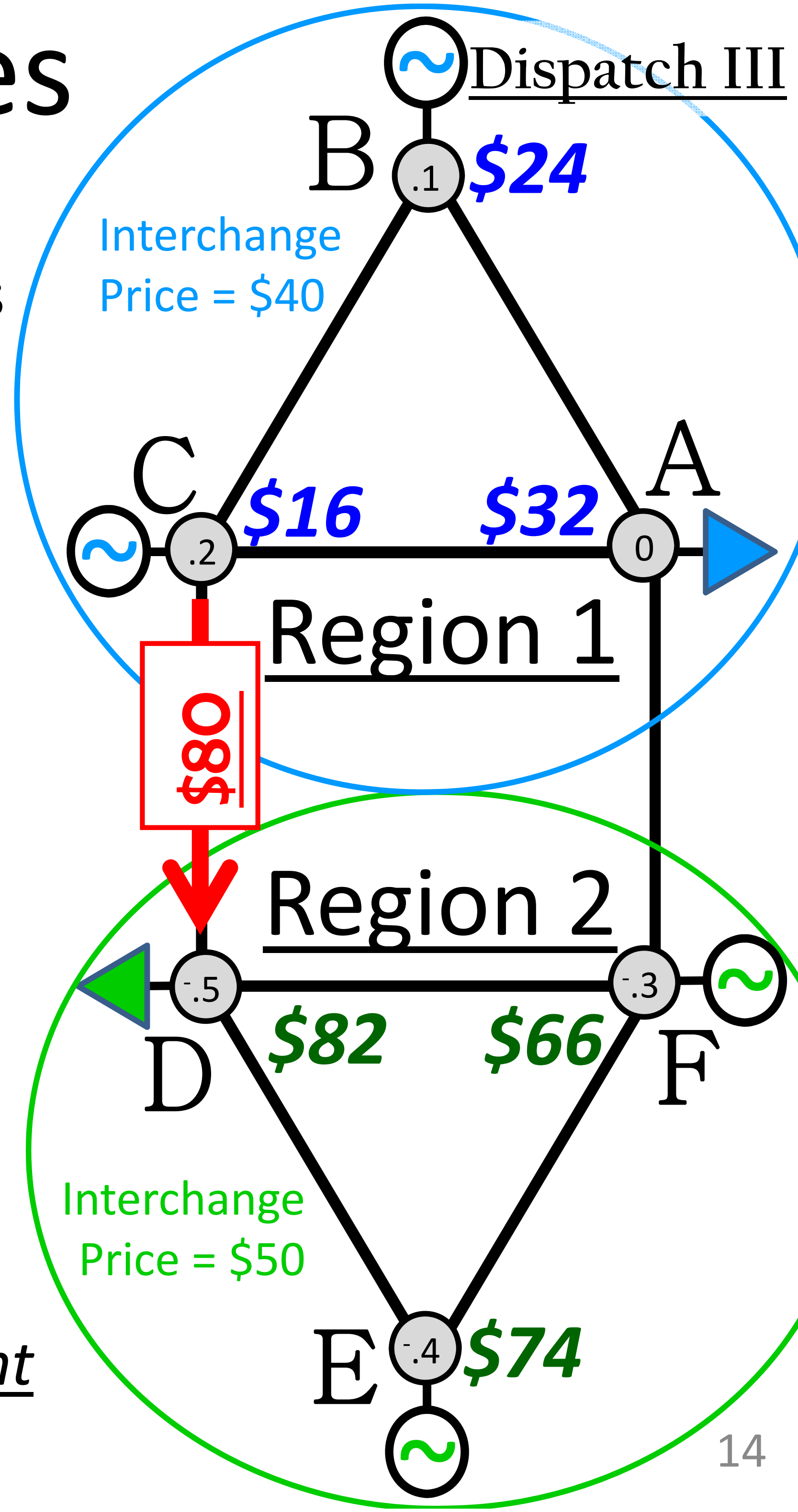
- Interface Price methodology used by MISO & PJM produces incorrect prices
  - Region 1 calculates Interface Price >= $65,
  - Region 2 calculates Interface Price <= $35
  - These prices should converge, but cannot
- Prices incentivize further transfers from Region 2 into Region 1, which would cause deviation from Joint Optimal Dispatch
- At Optimal Interchange level, Regions would pay at least $30 ($65 – $35) for transactions worth $0 at the margin.



RTOs' Interface Prices

at Sub-Optimal Interchange

- Previous slide noted that Interface Prices as currently calculated by MISO & PJM would provide incentive to increase R2-to-R1 schedules, which would move away from the Joint Optimal Dispatch
- Shown here is possible dispatch solution in which R2-to-R1 transfers continued beyond the Joint Optimal Dispatch
  - Interchange Price calculation assumes same redispatch pattern as previously: [-3, 2, -2, 3]
- Note that it is now more costly to support incremental interchange in Region 2 ($50) than Region 1 ($40) — *__We have Overshot Optimal Dispatch point__*



RTOs' Interface Prices

at Sub-Optimal Interchange

Same Dispatch as previous slide

Calculate Region 2 LMPs with R1 SCED:

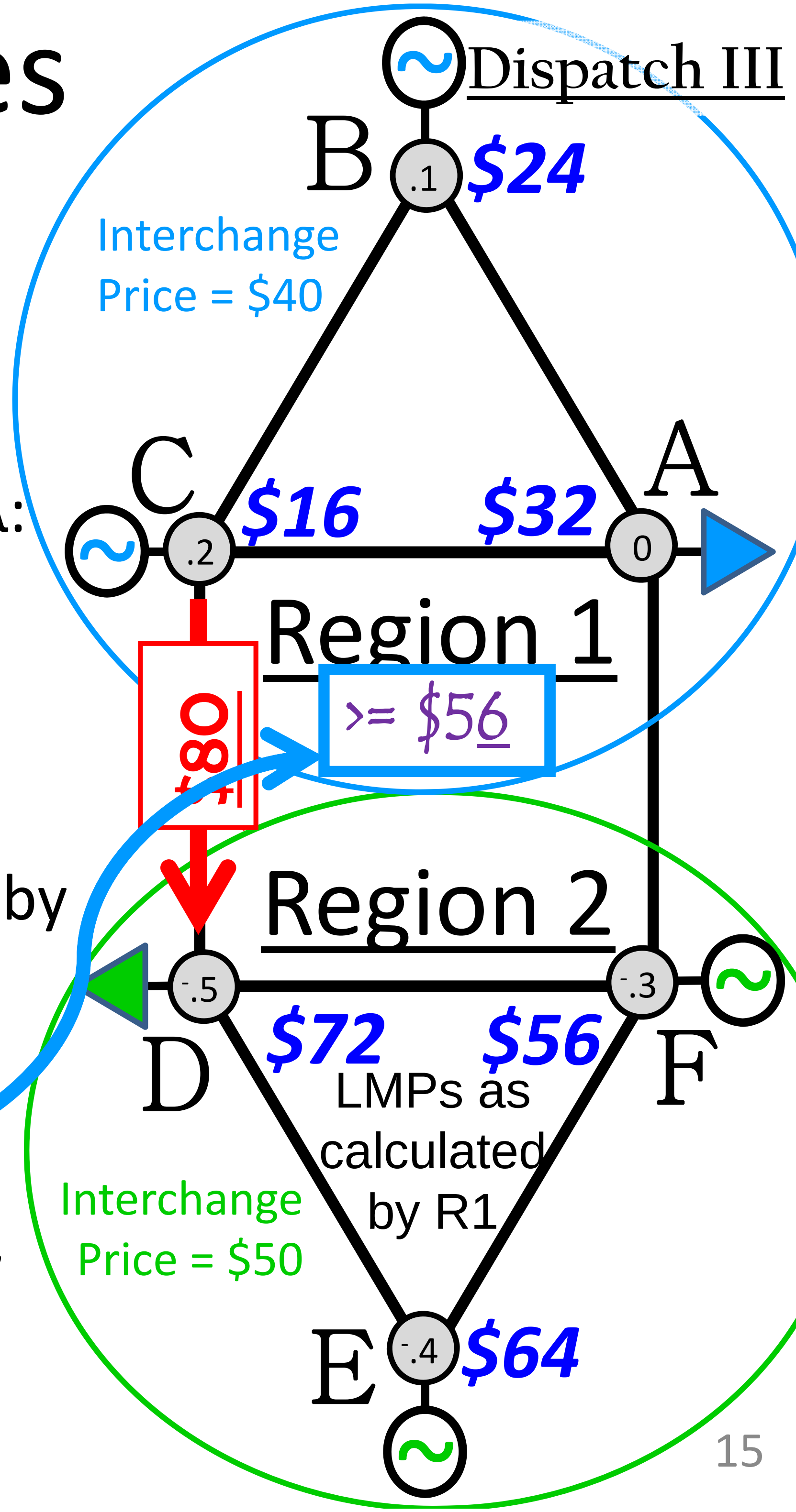
- Recall Relationship between DF, LMP & λ:

  $LMP_F - LMP_A = \lambda \times (DF_F - DF_A)$

  with $\lambda = -\$80$, and $DF_A = 0$, we get:

  $LMP_F = LMP_A + DF_F \times (-\$80) = \$56$

- Remaining Region-2 LMPs, as calculated by Region 1: $LMP_D = \$72$; $LMP_E = \$64$
- For any weights >= 0, Weighted Average of {56, 64, 72} >= $56
  - This is Interface Price calculated by Region 1, similar to current MISO/PJM approach



RTOs' Interface Prices

at Sub-Optimal Interchange

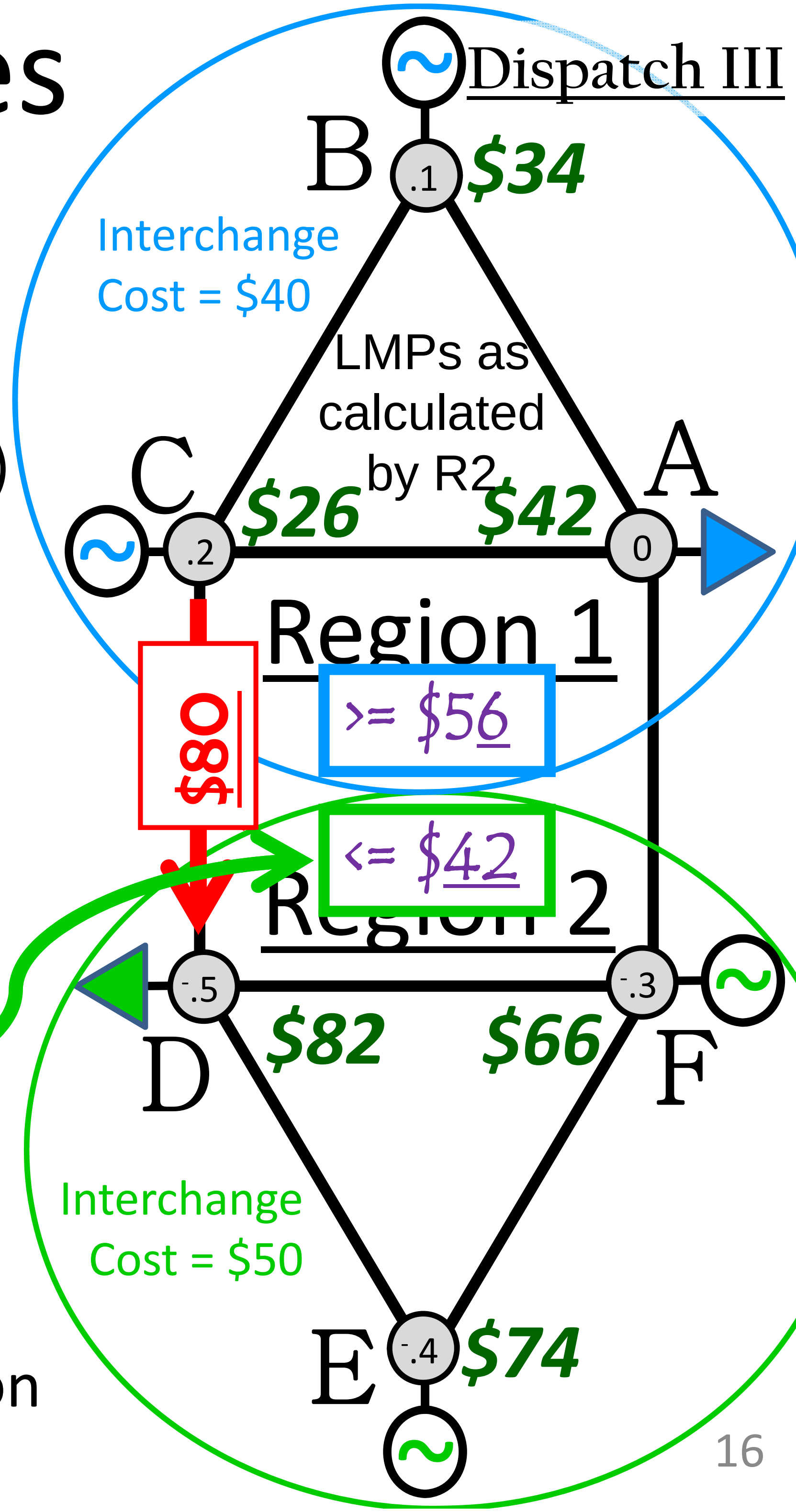
Use same approach to calculate Region 2 Interface Price: Weighted Average of R1 LMPs as calculated by R2 SCED (weights >=0)

- Relationship between DF, LMP & λ:

  $LMP_F – LMP_A = \lambda \times (DF_F – DF_A)$

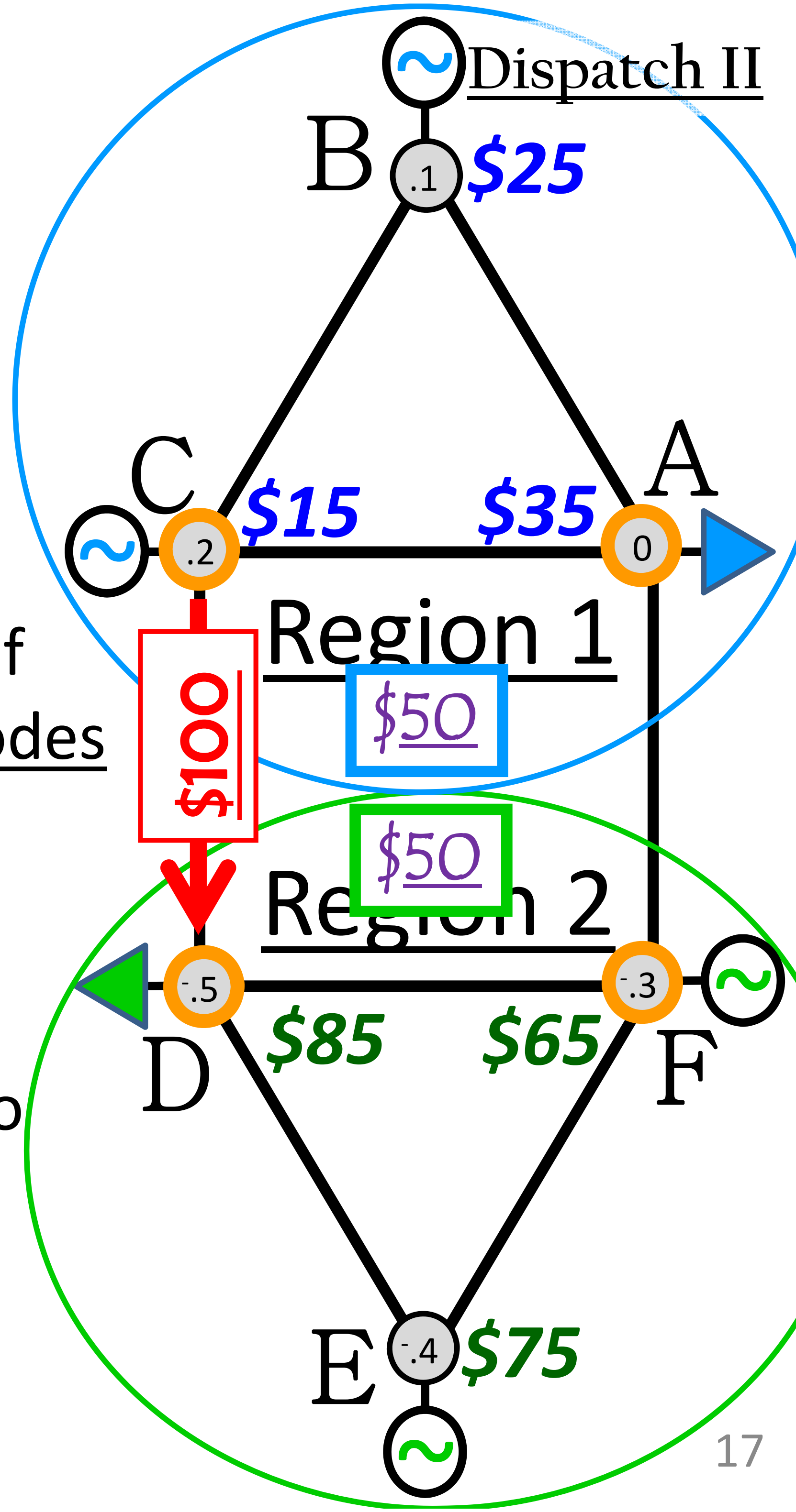
  with $\lambda = -\$80$, and $DF_A = 0$, we get:

  $LMP_A = LMP_F – DF_F \times (^{-}\$80) = \$42$
- Remaining Region 1 LMPs, as calculated by Region 2: $LMP_B = \$34$; $LMP_C = \$26$
- Interface Price <= $42
- MISO/PJM-style Interface Prices incent R2-to-R1 transfers, which is opposite the true direction of interchange optimization



Interface Pricing Alternatives

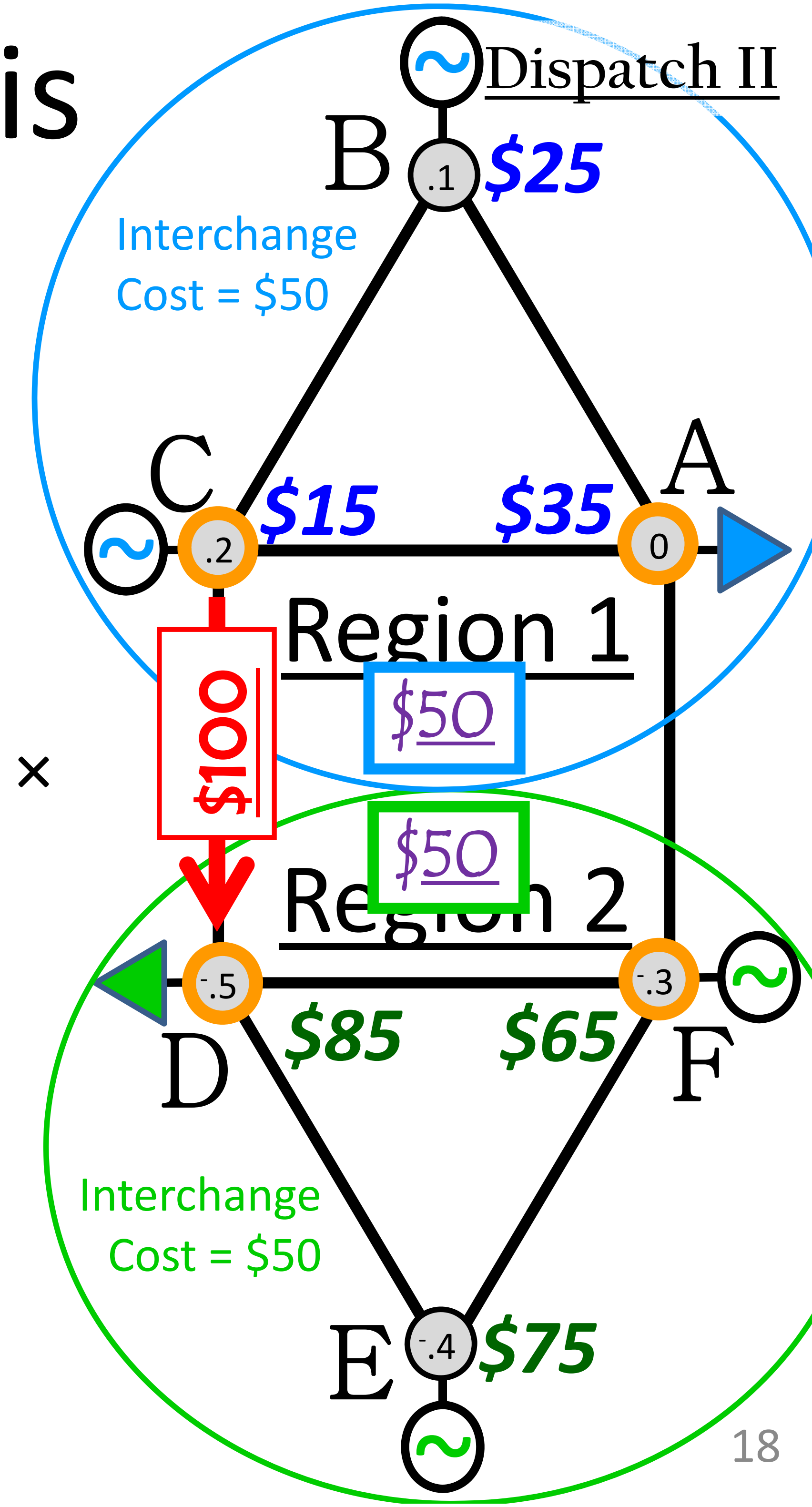
- Recall that, at Joint Optimal Dispatch, both Regions calculate the same set of Nodal LMPs for the entire Network
- Regions' Interface Prices will converge if (& only if) based on the Same Set of Nodes
- Consider new, common Interface Price: Average LMP at Nodes A, C, D & F
  - Avg {$15, $35, $65, $85} = $50
- Price Convergence provides incentive to schedule the optimal interchange level
- Advance inter-regional coordination of Redispatch Pattern now not necessary



Same-Nodes Price is True Marginal Cost

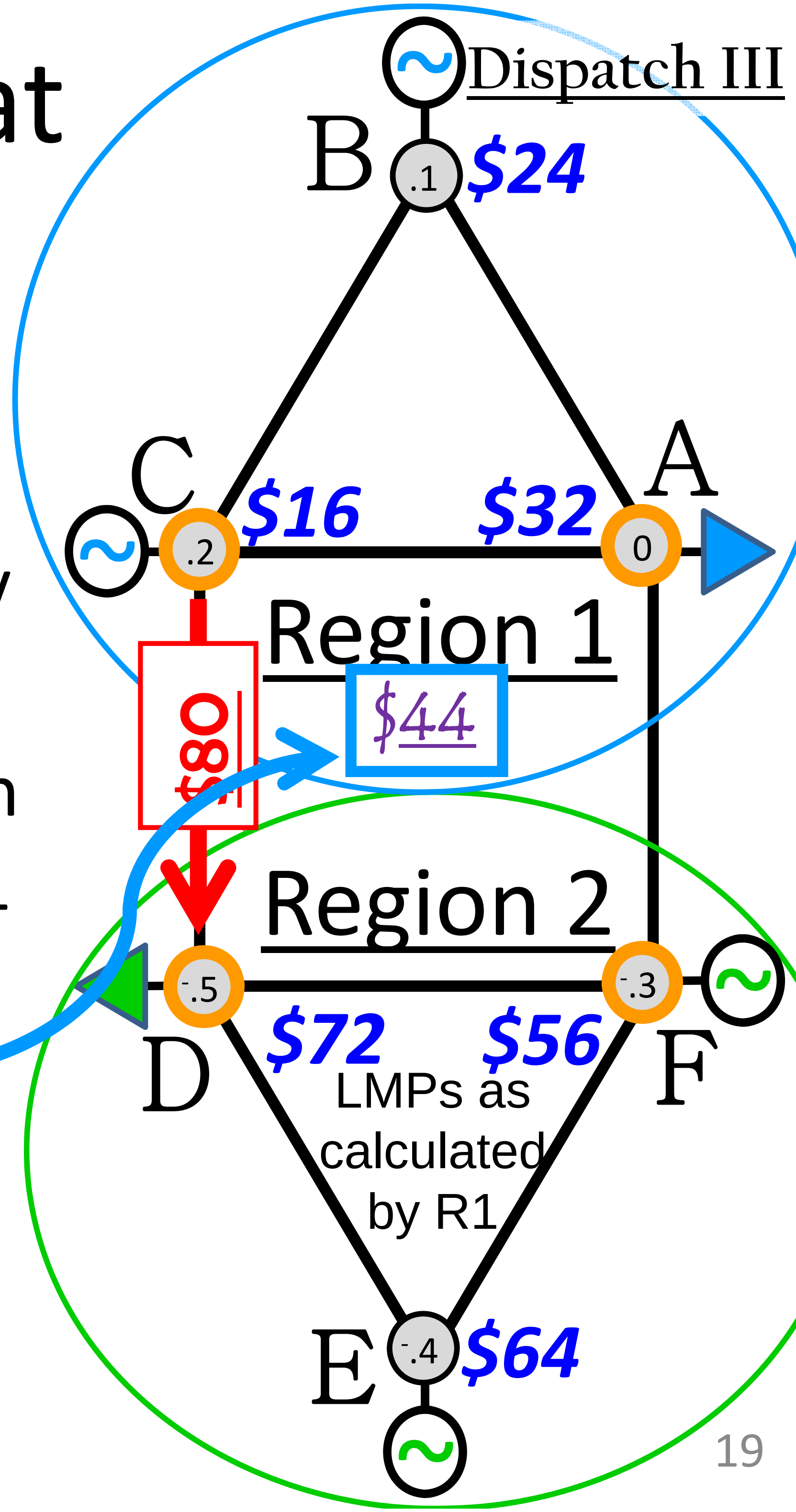
Consider cost for Region 1 to deliver 1 MW to [A, C, D, F] Interface:

- Increase Node C output by 1 MW, sink evenly among [A, C, D, F]
- Impact on C→D Constraint is 1 MW × (DF_C – Average {DF_A, DF_C, DF_D, DF_F}) = 1 × (.2 – ⁻.15) = .35 MW
- Offset C→D Impact with 3.5 MW transfer from B to C
- Cost = 15 + 3.5 × (25 – 15) = $50
- Region 2 Calculation also gives $50



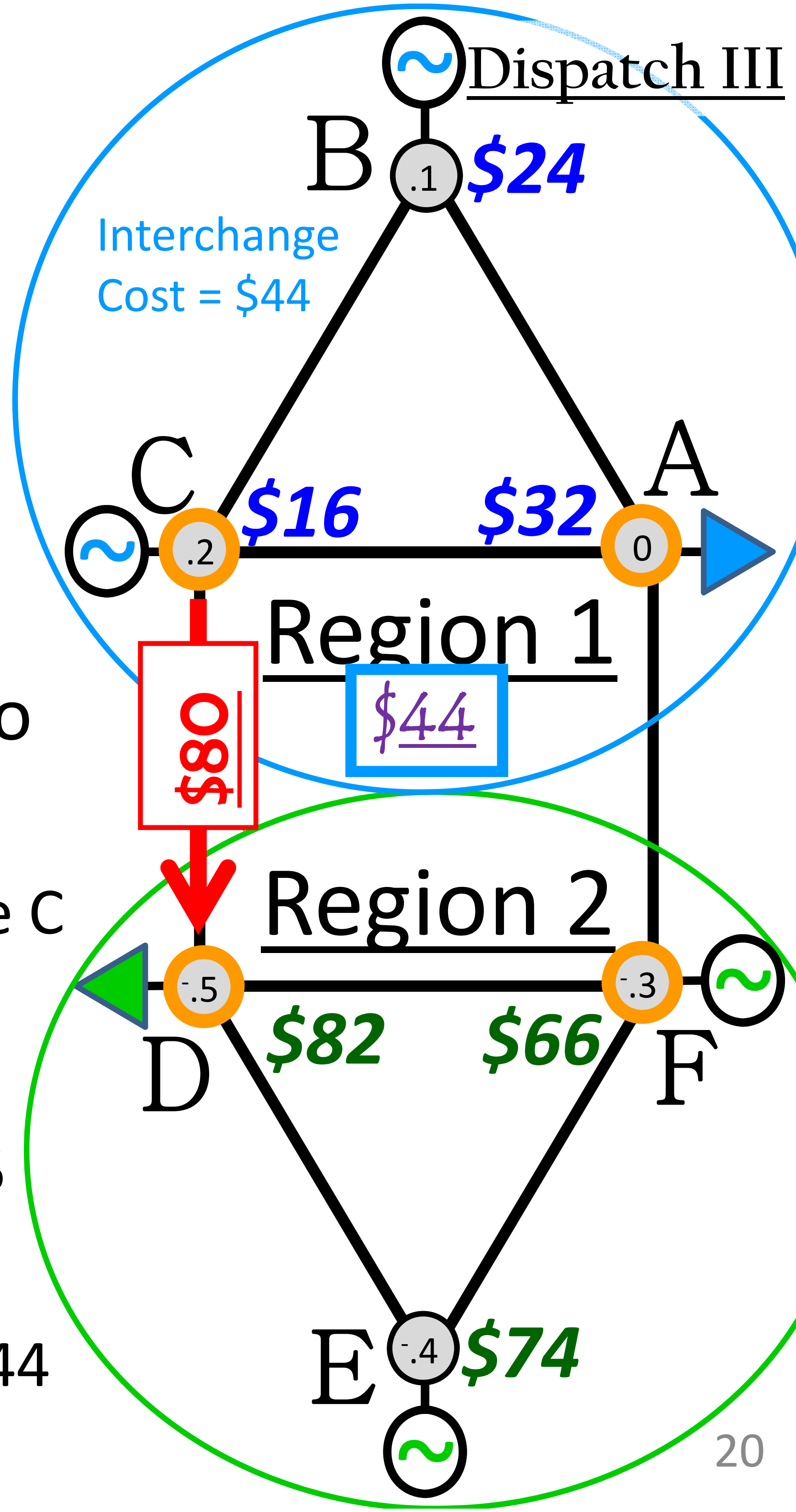
Same-Nodes Pricing at Sub-optimal Dispatch

- Consider the new Interface Price definition – Average LMP at Boundary Nodes A, C, D & F – away from the optimal interchange level
- Take previous Sub-optimal Dispatch and LMPs as calculated by Region 1
  - R1 calculates Interface Price as Average {$16, $32, $56, $72) = $44



Same-Nodes Price Calculation, R1

- Previous slide calculated Interface Price as Avg. [A, C, D ,F] LMP = $44
- This price can also be calculated as the incremental cost for Region 1 to deliver power to these nodes:
  - Assume 1 MW is delivered from Node C to [A, C, D, F] (evenly distributed)
  - Impact on C→D Constraint is 1 MW × DF_C – Average{DF_A, DF_C DF_D, DF_F} = .35
  - This requires 3.5 MW B-to-C dispatch
  - Cost = $LMP_C + 3.5 \times (LMP_B - LMP_C)$ = $44

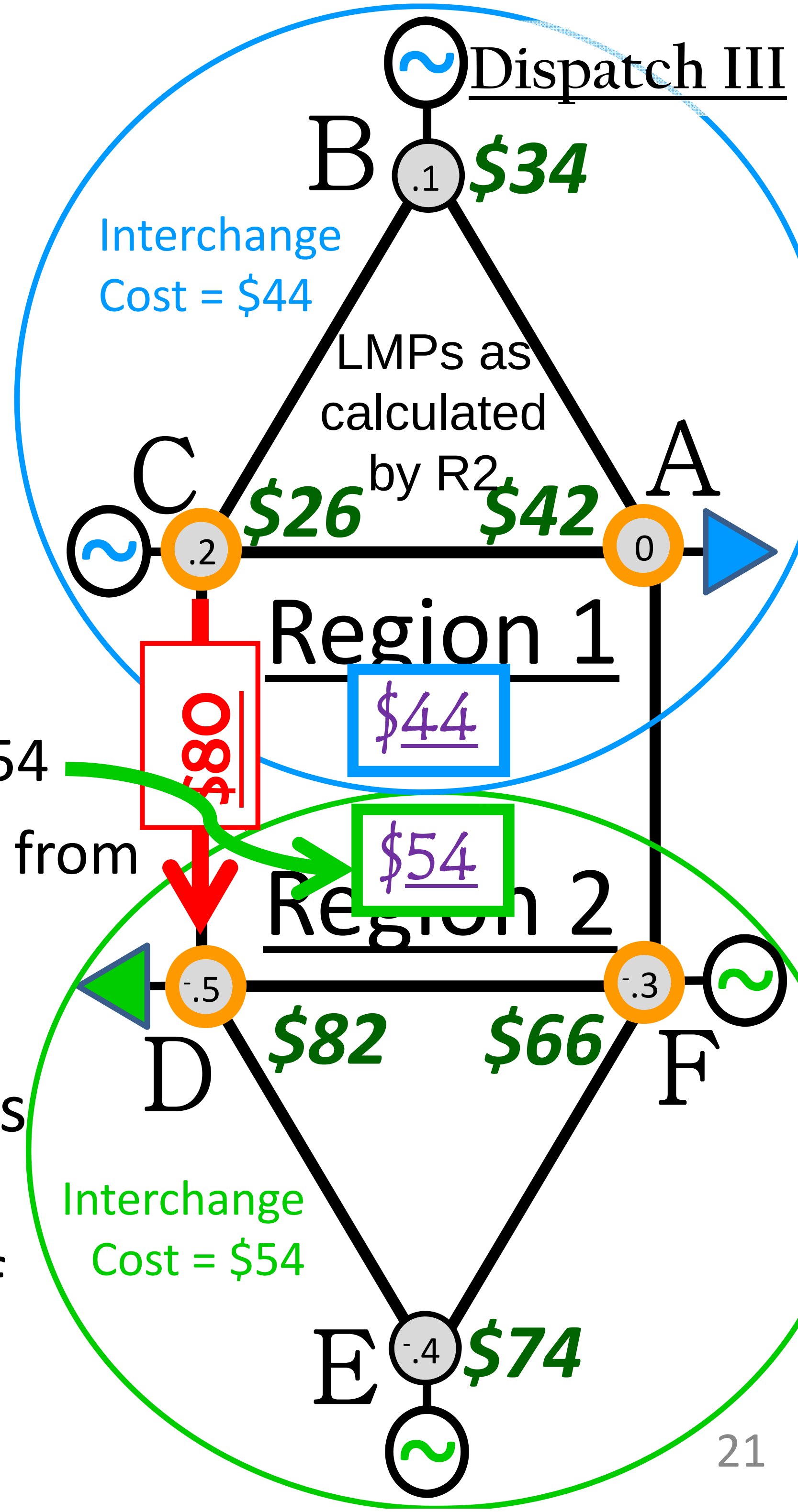


Same-Nodes Price Calculation, R2

Previous Sub-optimal Dispatch and LMPs as calculated by Region 2

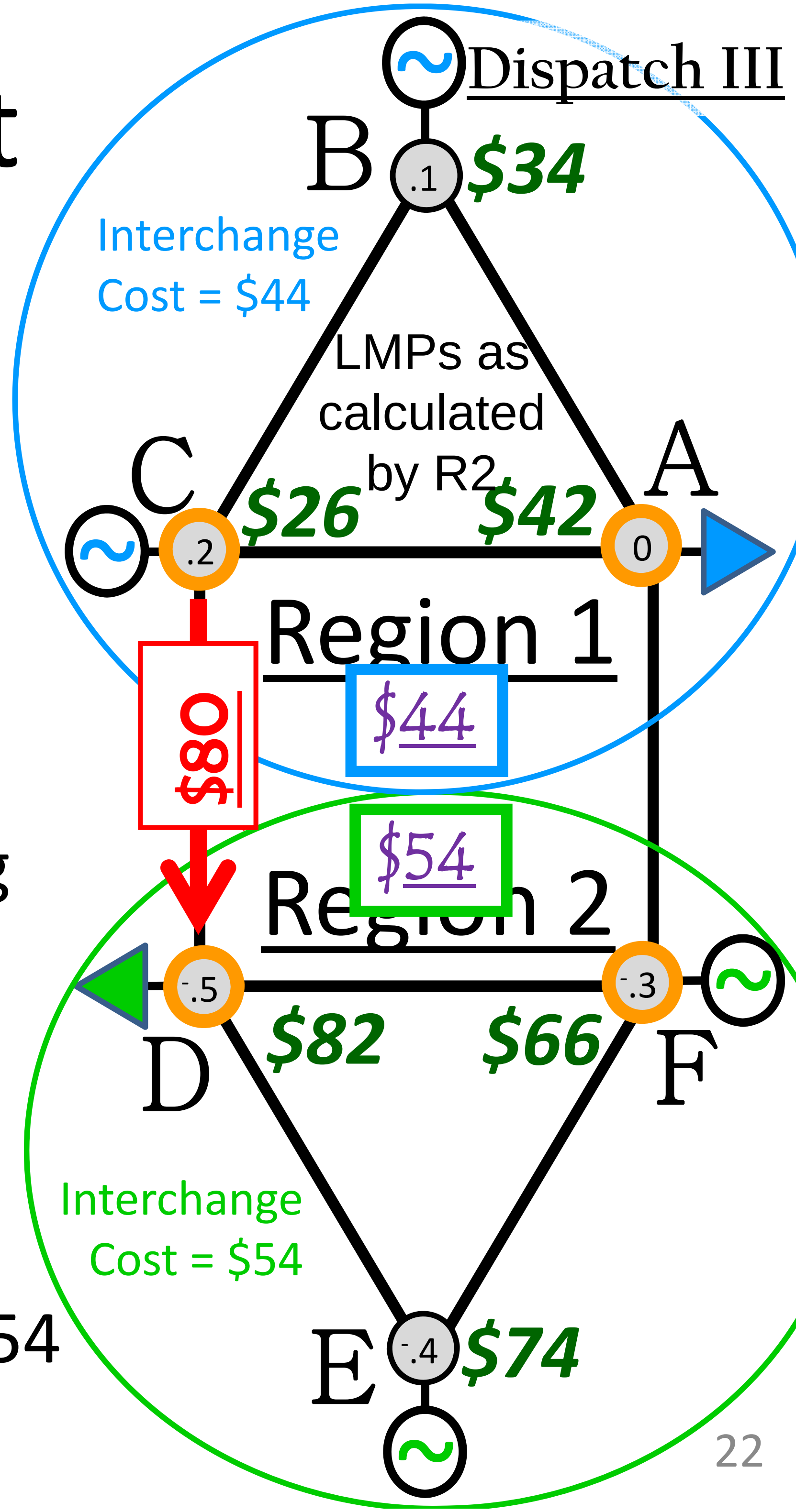
- Define Interface Price as Average LMP at boundary Nodes A, C, D & F
- Region-2-calculated Interface Price = $54
- This is also incremental cost of delivery from Region 2 to the [A, C, D, F] Interface, as calculated similar to previous slide

- Unlike MISO/PJM-type Interface Prices (weighted LMP average at <u>other</u> Region's nodes), using common set of nodes provides correct incentives



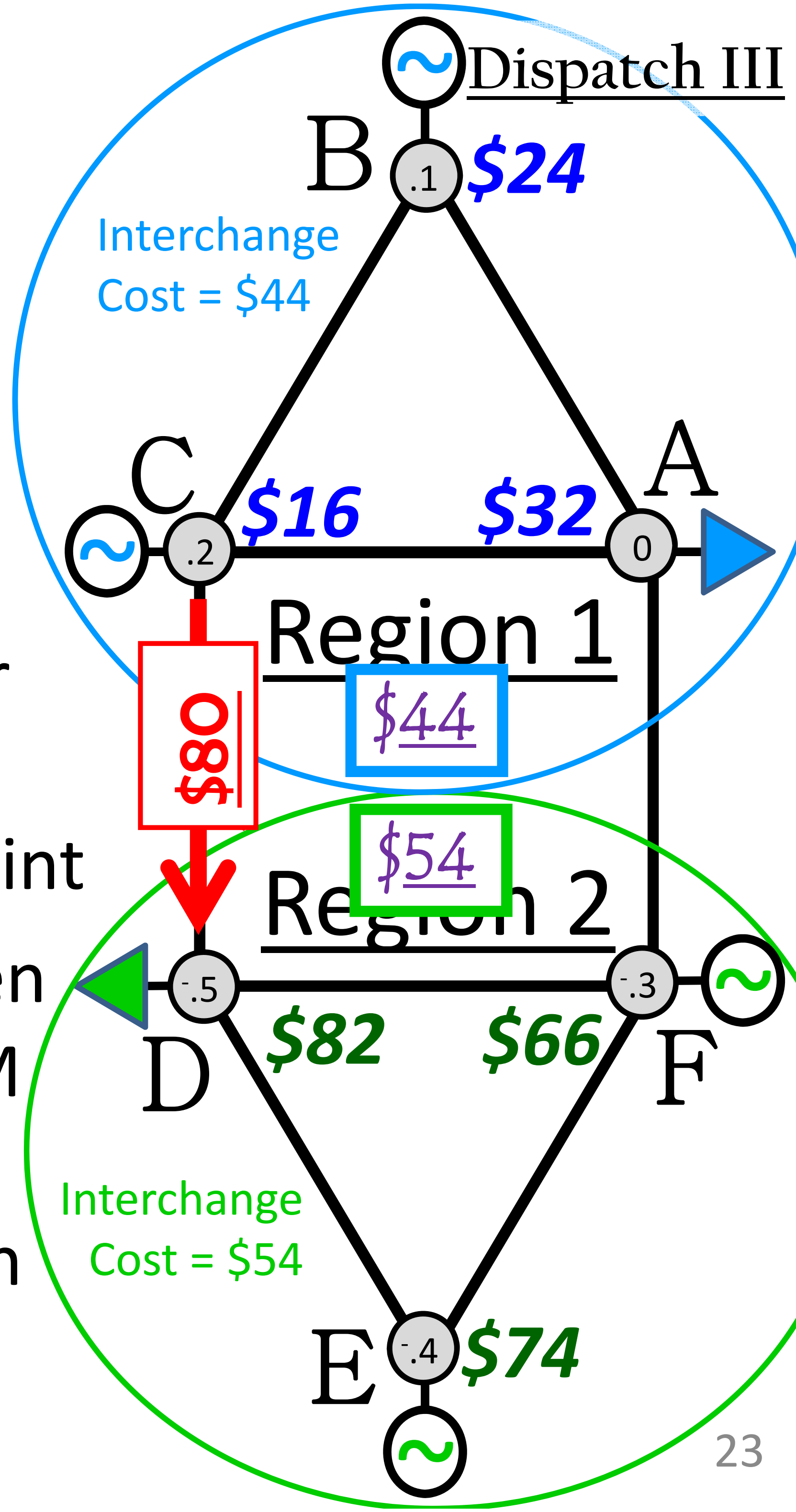
Interchange Settlement

- Interface Price Difference shows that incremental export from Region 1 to Region 2 is appropriate
- Interchange schedules would pay $44 to Region 1, and receive $54 from Region 2, netting $10
- These Schedules accomplish nothing the Regions could not accomplish themselves at lower cost
- Regions could instead schedule Interchange themselves, as in M2M, and settle at price between $44 & $54



Interchange/M2M Interaction

- As noted previously, specification of Interchange Redispatch pattern, or common nodes & weights for Interface Pricing, implies particular allocation of costs of managing incremental congestion on constraint
- The impact of transactions between the Regions, as calculated for M2M purposes, should be consistent with the cost allocation assumed in the Interface Price calculation

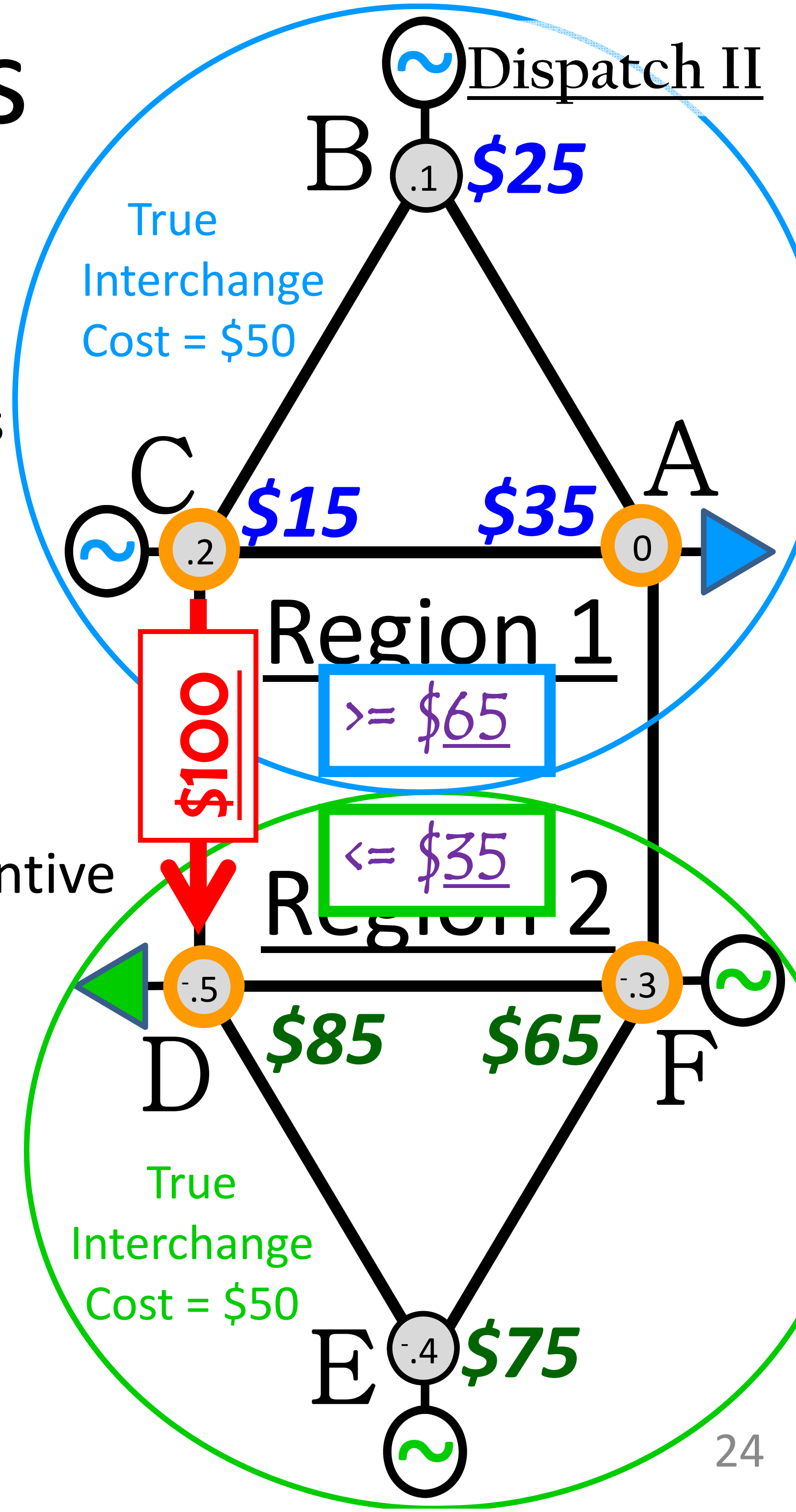


Implications for FTRs

Consider Internal FTRs in Region 1

Previous Optimal Dispatch & $50 cost of Interchange based on [A, C, D, F] Interface

- Assume this dispatch reflects no transactions
- Assume outstanding feasible FTR set corresponding to current dispatch
  - B-to-A FTRs MW quantity = Gen_B MW
  - C-to-A FTRs MW quantity = Gen_C MW
- FTRs can be just fully funded in this dispatch
- But current RTO pricing practice creates Incentive to schedule power from R2 into R1
- Each MW of incremental R2-to-R1 schedule reduces R1 Dispatch cost by $50, but entails Interchange settlement >=$65
- R1 FTRs can no longer be fully funded
- R2 Congestion Fund also loses money



Key Takeaways I

1. The Incremental Cost of Interchange for a Region depends on the allocation among Regions of the costs of managing incremental congestion on Binding Constraints
2. Given any specified allocation of these costs, Optimal 2-Region Dispatch corresponds to equal Interchange Incremental Costs (or Shadow Prices) as calculated by the 2 Regions
3. Congestion between Regions does not prevent convergence of the Interchange Shadow Prices in any way
4. The Interchange Shadow Price is the correct price for settling imports & exports, just as the nodal LMP is the correct price for settling nodal injections
5. Deviation from this price violates the principle of Marginal-Cost Pricing, may lead to Congestion Fund underfunding, & gives inefficient scheduling incentives

Key Takeaways II

6. The approach used by MISO & PJM — Weighted Average of Other-Region LMPs, with non-negative weights — is incapable of producing the correct price in this very simple example, and it appears highly implausible that a fixed weighting can yield appropriate prices in the actual MISO–PJM system over a wide range of dispatches and binding constraints
7. In contrast, when both Regions determine Interface Prices based on a common set of nodes and node weightings, Interface Prices provide economically correct signals
8. The current MISO & PJM practice of relying on third-party arbitrageurs results in higher costs to load than necessary; The RTOs could instead schedule interchange directly and retain any price-spread surplus, as they do in M2M