Temporal Opportunity Cost for Energy Storage Resources (ESR) Real Time Cost Offer

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Topics/Agenda

1. Temporal Opportunity Cost (TOC) Concept: Cost Offer to Discharge
2. Cost Calculation Proposal
3. Temporal Opportunity Cost Calculator (TOCC)
4. Example
   - Assumptions
   - 24 Hour Schedule
   - Economic Cost Calculation
5. Appendix
   - Temporal Opportunity Benefit (TOB) Concept: Cost Offer to Charge
   - Example
   - Operationally Limited Analog

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Temporal Opportunity Cost Concept - DISCHARGE

Opportunity Cost

1. The value of stored energy is the revenue earned at discharge
2. A rational operator and market will discharge at highest available prices
3. The marginal discharge will be the lowest of those high prices
4. The opportunity cost of stored energy is the marginal discharge

Replacement Cost

1. Rather than missing an opportunity to discharge, an ESR may be able to replace energy
2. A rational operator and market will charge at lowest available prices
3. The marginal charge will be the lowest of those available prices
4. The replacement cost of a charge is the marginal charge cost

The **TOC** of stored energy is the **minimum** of the opportunity and replacement costs.

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Cost Calculation Proposal

- PJM provides a temporal opportunity cost calculator (TOCC) that yields the optimal schedule for each ESR
  - Optimal schedule maximizes unit margin subject to unit capabilities, state of charge (owner provided), and forecast Real Time LMP
  - Cleared Day Ahead LMP used as forecast Real Time LMP
- Replacement and Opportunity costs are calculated using the optimal schedule
- TOC is set to minimum of calculated opportunity and replacement costs
- Recalculated every hour for each ESR
  - However this proposal doesn't preclude ESR using another method for calculating its cost offer as long as approved and consistently used
- This proposed calculator is meant for cost offers only. Resource owners would continue to be responsible for DA/RT optimization and maintaining state of charge.

TOCC for Optimal RT Schedule

- Unit dispatch not system dispatch
- Use static LMP for all hours of the day in calculator
  - Simpler optimization problem
  - Practical implementation
- Parameters include efficiency, start time, and other limits
- Consistently derived LMPs
  - Day Ahead LMP or forecast Real Time LMP, but not mix of both
- Should include next day Day Ahead solution when available

Sample Assumptions

- ESR has a 4 MWh capacity
- ESR can charge or discharge 1 MWh per hour
- Operating schedule determined by TOCC using known DA LMPs
- Economic cost calculated for hour assuming ESR directed to deviate from TOCC schedule
- Sample shows State of Charge (SOC) for TOCC schedule

Sample TOCC: 24 Hour Optimal Schedule

HE	DA LMP	DA LMP/Eff.	Beg. SOC	Op. Plan	End SOC
1	$44	$55		Charge	
2	$48	$60		Charge	
3	$52	$65		Charge	
4	$56	$70		Charge	
5	$68	$85			
6	$72	$90			
7	$94	$118			
8	$104	$130		Gen	
9	$108	$135		Gen	
10	$100	$125		Gen	
11	$112	$140		Gen	
12	$96	$120			

HE	DA LMP	DA LMP/Eff.	Beg. SOC	Op. Plan	End SOC
13	$76	$95		Charge	
14	$72	$90		Charge	
15	$64	$80		Charge	
16	$64	$80		Charge	
17	$80	$100			
18	$96	$120		Gen	
19	$112	$140		Gen	
20	$116	$145		Gen	
21	$108	$135		Gen	
22	$92	$115			
23	$84	$105			
24	$72	$90			

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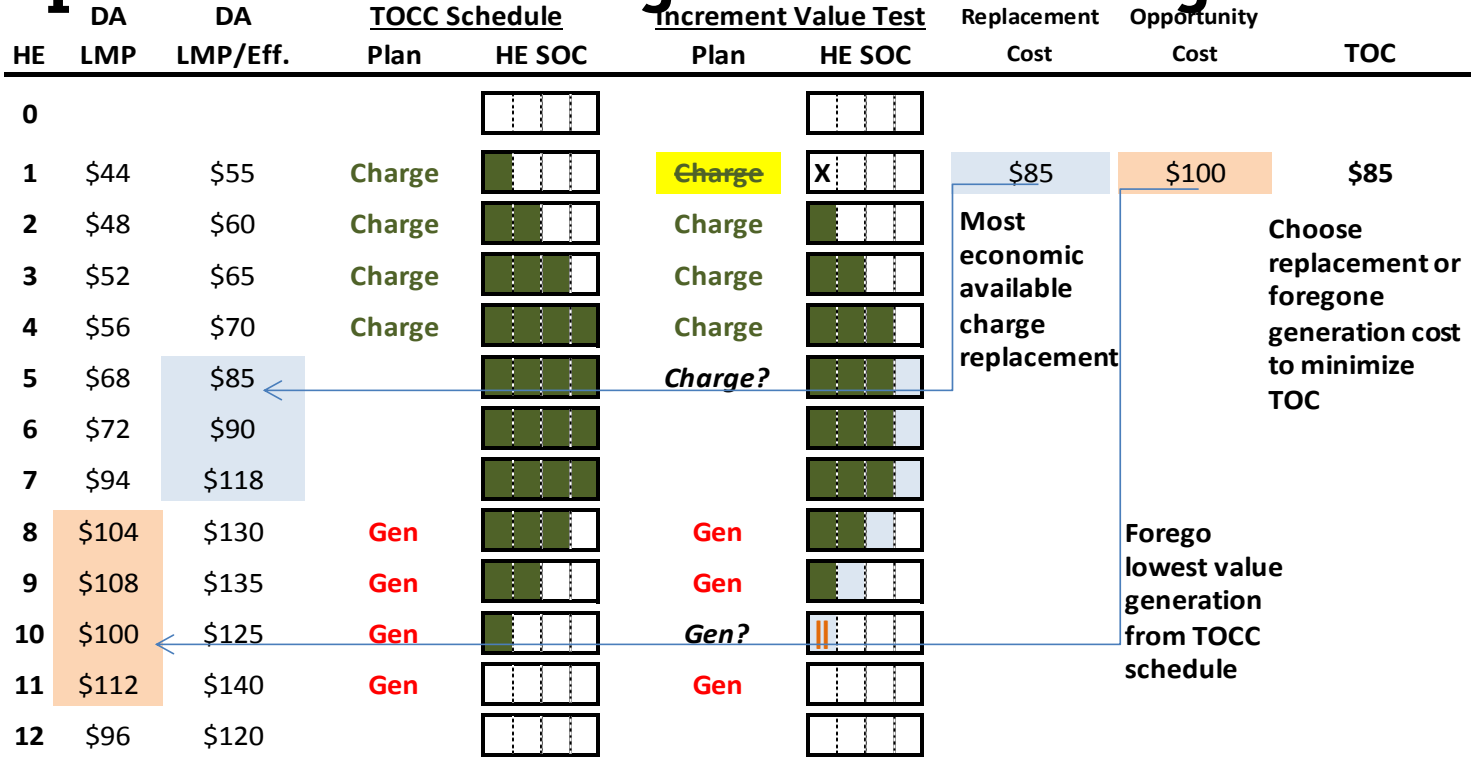
Sample TOCC: Discharge/Blocked Charge 1



* DA LMP/Eff. = cost to charge = DA LMP/Efficiency where efficiency assumed @80% for illustration.
Example: Hour 5 DA LMP of $68/80% efficiency = $85 cost to charge

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Sample TOCC: Discharge/Blocked Charge 2

HE	DA LMP	DA LMP/Eff.	TOCC Schedule Plan	TOCC Schedule HE SOC	Increment Value Test Plan	Increment Value Test HE SOC	Replacement Cost	Opportunity Cost	TOC
4	$56	$70	Charge		Charge				
5	$68	$85			Gen	X	$90	$100	**$90**
6	$72	$90			*Charge?*				
7	$94	$118							
8	$104	$130	Gen		Gen				
9	$108	$135	Gen		Gen				
10	$100	$125	Gen		*Gen?*				
11	$112	$140	Gen		Gen				
12	$96	$120							

Most economic available charge replacement

Forego lowest value generation from TOCC schedule

Choose replacement or foregone generation cost to minimize TOC

Potential opportunity cost: LMP from hours where TOCC optimal schedule has unit generating

Potential replacement cost: LMP from hours where TOCC optimal schedule has unit idle

* DA LMP/Eff. = cost to charge = DA LMP/Efficiency where efficiency assumed @80% for illustration.

Example: Hour 5 DA LMP of $68/80% efficiency = $85 cost to charge

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Appendix

Temporal Opportunity Benefit Concept - CHARGE

Opportunity Credit

1. A forced charge or blocked discharge creates or retains stored energy
2. A rational operator and market will discharge stored energy at highest available prices
3. The marginal discharge will be the lowest of those high prices
4. The opportunity credit for stored energy is the marginal discharge

Avoided Replacement Credit

1. Rather than adding an opportunity to discharge, an ESR may be able to avoid charging
2. A rational operator and market will charge at lowest available prices
3. The marginal charge will be the lowest of those available prices
4. The avoided replacement credit of a charge is the marginal charge cost

The **temporal opportunity benefit** is the **max** of the opportunity and replacement costs.

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Sample TOCC: Charge/Blocked Discharge

HE	DA LMP	DA LMP/Eff.	TOCC Schedule Plan	TOCC Schedule HE SOC	Increment Value Test Plan	Increment Value Test HE SOC	Credit Avoided Replacement	Credit Gen Opportunity	Net Replacement	Net Opportunity	Buy Price
7											
8	$104	$130	Gen		~~Gen~~		$95	$96	$9	$8	$96
9	$108	$135	Gen		Gen						
10	$100	$125	Gen		Gen						
11	$112	$140	Gen		Gen						
12	$96	$120			*Gen?*						
13	$76	$95	Charge		*Charge?*						
14	$72	$90	Charge		Charge						
15	$64	$80	Charge		Charge						
16	$64	$80	Charge		Charge						
17	$80	$100									
18	$96	$120	Gen		Gen						
19	$112	$140	Gen		Gen						
20	$116	$145	Gen		Gen						
21	$108	$135	Gen		Gen						
22	$92	$115									

Most expensive planned charge avoided from TOCC schedule

Most valuable generation opportunity available from TOCC schedule

Choose avoided replacement or generation opportunity to minimize net cost

Potential generation opportunity credit: LMP from hours where TOCC optimal schedule has unit idle

Potential avoided replacement credit: LMP from hours where TOCC optimal schedule has unit charging

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OPC Analogues to TOCC

Operationally Limited Opportunity Cost

1. Unit has emission limits
2. A run today may limit run later
3. Opportunity Cost Calculator (OPC) generates a cost-based adder that “optimizes” potential run hours
   - Uses forecasted commodity spreads
4. Evaluated daily

Limited Energy Opportunity Cost

1. Unit has charge limitations
2. A run this interval may limit a run later
3. Temporal Opportunity Cost Calculator (TOCC) generates a cost-based price that “optimizes” potential run hours
   - Uses forecasted temporal spreads
4. Evaluated hourly