Economics of Grid-Supported Electric Power Markets: A Fundamental Reconsideration

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Planning Efficiency Through Improved Software)
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NOTE: This presentation briefly reviews key points from the following document

Ref. [1] L. Tesfatsion (2023), **Economics of Grid-Supported Electric Power Markets: A Fundamental Reconsideration,** Supporting Document for Comments (Accession #20230117-5051, 65pp.) e-filed by L. Tesfatsion to the U.S. Federal Energy Regulatory Commission for Docket #AD21-10-000 ("Modernizing Wholesale Electricity Market Design")

https://www2.econ.iastate.edu/tesfatsi/LeighTesfatsion.EFiledComments.FERC.AD21-10-000.pdf

Presentation Outline

- ☐ **Major Problem:** U.S. RTO/ISO-managed wholesale power markets are currently experiencing increasingly volatile and uncertain net load due to increasing reliance on renewable power and increasingly diverse types of market participants.

- ☐ **Major Concern:** Three conceptually-problematic market-design aspects -- product definition & pricing, settlement timing, and supply-offer formulations -- are hindering attempts to remedy this major problem.

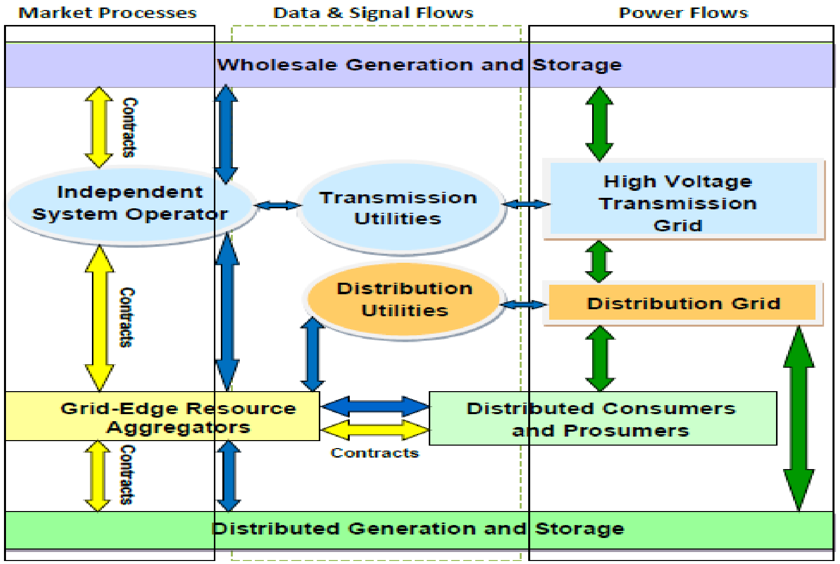
- ☐ **Possible Remedy:**
  - — An alternative conceptually-consistent **Linked Swing-Contract Market Design** has been proposed, developed, and tested at Technology Readiness Level TRL-3.
  - — This alternative design is well-suited for scalable, efficient, & reliable support of increasingly decarbonized grid operations with increasingly diverse participants.
  - — Adoption of this alternative design by current RTO/ISO-managed markets would require changes in product definitions, settlement rules, and supply-offer forms, but not in real-time operations.
  - — Thus, adoption of this alternative design could proceed by gradual transition.

- ☐ **References**

Overview: U.S. RTO/ISO-Managed Wholesale Power Markets

- U.S. electric power systems are linked **T**ransmission & **D**istribution (**T&D**) systems consisting of complex intertwined economic, technological, and physical processes.

Fig. 1: *Depiction of a U.S. Electric Power System as a linked T&D system*



- This presentation focuses on critical issues currently facing U.S. electric power systems at the high-voltage transmission level.
- Attention is focused on market-design concerns arising for U.S. grid-supported wholesale power markets centrally managed by an **I**ndependent **S**ystem **O**perator (**ISO**) or **R**egional **T**ransmission **O**rganization (**RTO**).
- Conceptually-coherent product definitions, settlement rules, and bid/offer formulations – able to cope effectively with increasing climate-change & power-resource diversification pressures -- have not yet been achieved for these markets.

U.S. RTO/ISO-Managed Markets … *Continued*

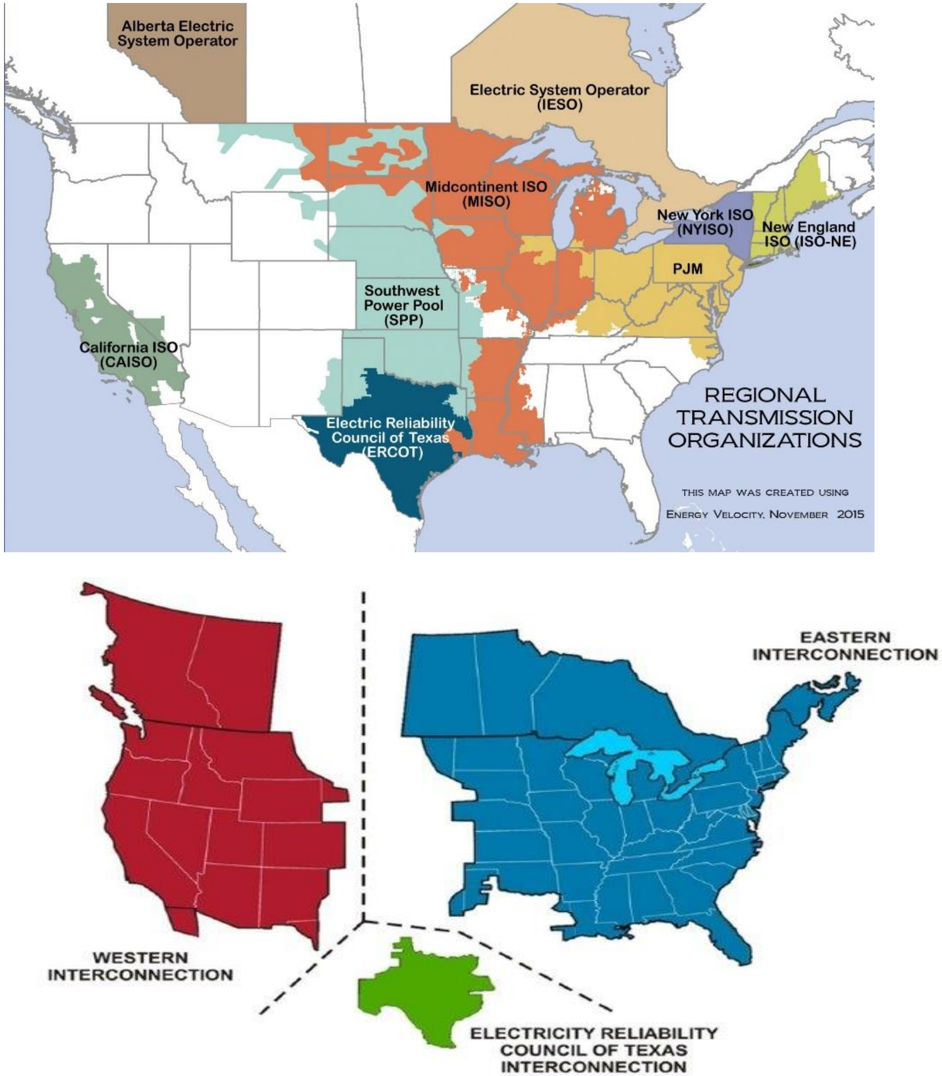


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Fig. 2: *Seven U.S. RTOs/ISOs -- CAISO, ERCOT, ISO-NE, MISO, NYISO, PJM, SPP -- operate over a high-voltage AC transmission grid consisting of three separately-synchronized parts.*

U.S. RTO/ISO-Managed Markets … *Continued*

Major Problem:

- Increasing reliance on *Intermittent* ***Power Resources*** ***(IPRs)***
  (e.g., wind farms & large solar PV panel arrays ***not*** fully firmed by storage)
- Increasing encouragement of more active participation by *distribution-level* power resources and customers (*FERC Order 2222, Final Rule, 17 September 2020*)

➡ **Increasing Volatility and Uncertainty of Real-Time Net Load**

[Net Load] =: [Power Withdrawals **+** Power Losses **–** Non-Dispatched Power Injections**]**

➡ **Increasing Volumetric Grid Risk** (*Grid power outflow ≠ Grid power inflow*)

- **RTOs/ISOs** must operate as ***"fiduciary conductors"*** tasked with orchestrating:
  - — *advance* availability and *just-in-time* dispatch of *increasingly diverse* power resources
  - — to service *just-in-time* power demands of *increasingly diverse* customers
  - — while meeting *just-in-time* power requirements for grid reliability.
- **Grids** must function as ***"flexibility-support mechanisms"***

U.S. RTO/ISO-Managed Markets … *Continued*

Potential Remedy for Major Problem

Increase dependable advance availability of flexible dispatchable power-production capabilities …

- **from wholesale-level power resources**
  - *Ensure revenue sufficiency* for essential suppliers
  - *Firm-up the RTO/ISO-dispatchability* of **I**ntermittent **P**ower **R**esources (**IPR**s)

- **from distribution-level power resources (FERC Order 2222)**
  - *Implement **T**ransactive **E**nergy **S**ystem (**TES**) designs* that permit aggregators (T&D linkage entities) to participate in wholesale power markets as suppliers of RTO/ISO-dispatchable power flows harnessed contractually from managed collections of diverse distributed power resources.

Market-Design Concerns

Conceptually-problematic legacy market-design features affecting operations in RTO/ISO-managed markets are *hindering* pursuit of this potential remedy.

U.S. RTO/ISO-Managed Markets … *Continued*

1. Product Definition & Pricing Issues (Short-to-Long Resource Planning)

- **Primary stress** on locational marginal pricing ($/MWh) for energy delivery (MWh) scheduled in short-term markets (DAM/RTM) for near-term operating periods.
- **Secondary stress** on RTO/ISO procurement of ancillary services – e.g., *unencumbered generation capacity* (MW) and *ramp* (MW/min) – to support the continual real-time balancing of net load across the grid.

Problem: Strong Product Correlation

➢ *These ancillary services are not independently-produced products.* Rather, they are the strongly-correlated ("jointly produced") physical attributes of the individual flows of power (MW) available for possible RTO/ISO dispatch at designated grid locations during designated time periods whose dispatched accumulations determine energy deliveries (MWh) at these locations for these time periods.

➢ This *strong product correlation* greatly limits the ability of these ancillary services to support scheduled energy deliveries & to ensure, more generally, the continual real-time balancing of net load across the grid.

⇒ *Growing need for **Out-of-Market (OOM) dispatch & uplift payments** to ensure continual real-time balancing of increasingly volatile & uncertain net load.*

Market-Design Concerns … *Continued*

2. Settlement Timing Issues: (Time-Inconsistent Payments)

- Payment for market-scheduled performance (energy delivery) prior to verified actual performance

⇨ *growing need for* ***ex-post payment adjustments****.*

3. Supply-Offer Issues: (Supplier Revenue Insufficiency)

- Reliance on conceptually-problematic *two-part partition* of supplier cost into static "variable" and "fixed" components;
- Narrow focus on ensuring market-revenue coverage of start-up cost ($/start), production cost ($/MWh) for grid-delivered energy (MWh), & opportunity cost ($/MW) for unencumbered generation capacity (MW)

⇨ *growing need for* ***OOM make-whole payments*** *to ensure the solvency -- i.e., revenue sufficiency [revenue ≥ avoidable cost] -- of market-cleared suppliers.*

The Linked Swing-Contract Market Design: Ref. [2]

A Conceptually-Consistent Alternative

Purpose:

Facilitation of transition to efficient reliable decarbonized grid operations & FERC Order 2222 initiatives

Key Design Differences:

-- Conceptually-coherent product definitions, time-consistent settlements, & flexible supply offer forms

-- Insurance approach that permits efficient reliable long-to-short resource planning as well as assured supplier revenue sufficiency.

Linked Collection of Forward Reserve Markets M(T) for Future Operating Periods T:

Market look-ahead horizons LAH(T) and operating periods T can vary in duration from years to minutes.

Reserve for T = Physically-Covered Insurance for T:

Guaranteed availability of power-production capabilities offered in advance of T by ***D***ispatchable ***P***ower ***R***esources (***DPRs***) for possible RTO/ISO dispatch during T to protect against volumetric grid risk.

Reserve Offers = Insurance Contracts:

Swing-contracts in two-part pricing form permit DPRs participating in a market M(T) to offer reserve for T with "swing" (flexibility) in physical attributes and with assurance of revenue sufficiency.

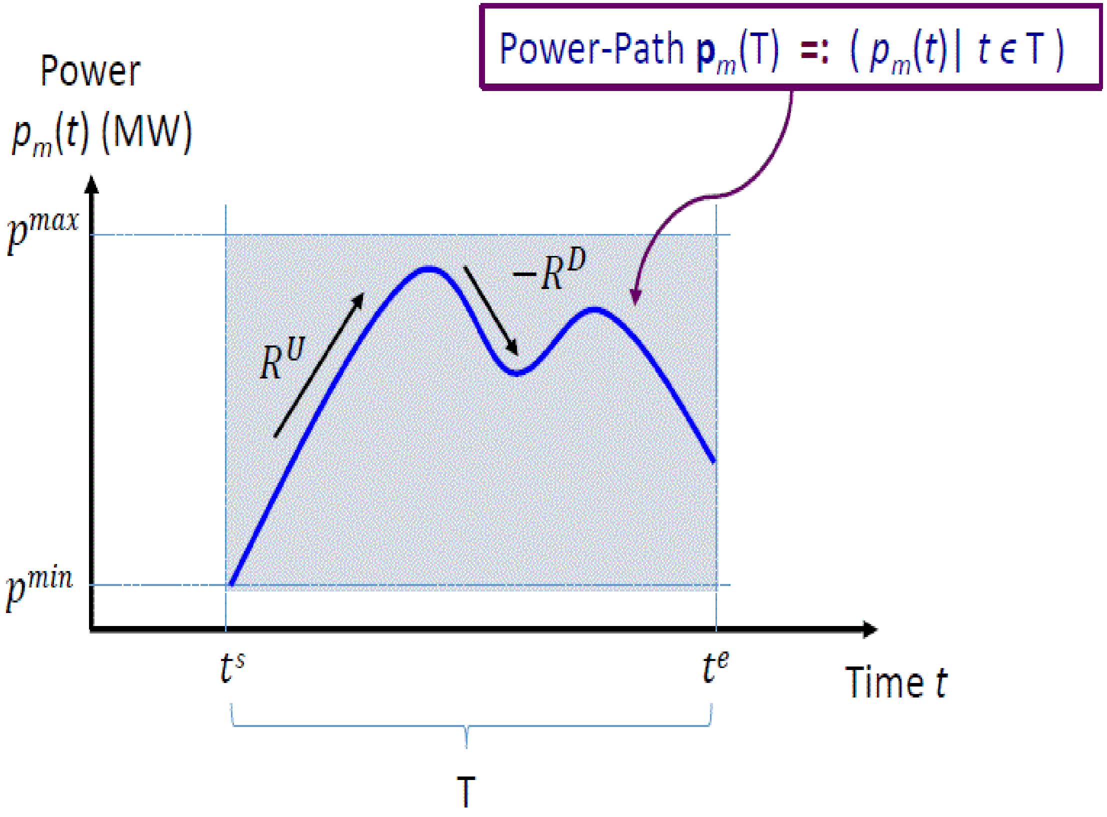
RTO/ISO Optimal Contract-Clearing for M(T):

Objective: Max expected net benefit of M(T) participants, subject to nodal-based system constraints

First Key Design Innovation: A New Product Conceptualization

- **Conceptualization of a "power-path"** as the fundamental product that ought to be transacted in grid-supported centrally-managed wholesale power markets.

Fig. 3: A ***power-path*** $\boldsymbol{p_m(T) =: (p_m(t) \mid t \in T)}$ *offered by a dispatchable power resource m for a future operating-period T is a sequence of injections and/or withdrawals of power* $p_m(t)$ *(MW) to take place at a* <u>*single*</u> *designated grid location b(m) during T .*



- **Support for Incentive Alignment**

This power-path product conceptualization permits designs for grid-supported centrally-managed wholesale power markets to align the *local goals and constraints of distributed market participants* with the *system goals and constraints of the central manager.*

Second Key Design Innovation: Reserve Offers in 2-Part Pricing Swing-Contract Form

- Let ***m*** denote a *Dispatchable Power Resource (DPR)* participating in an RTO/ISO-managed reserve market M(T) for a future operating period T.
- The *reserve offer* submitted to M(T) by *m* takes the *swing-contract form*:

$$\mathrm{SC}_m = \left(\alpha_m, \mathbb{T}_m^{\mathrm{ex}}, \mathbb{PP}_m, \phi_m\right)$$

- The swing contract SC_m consists of **four components specified by *m***:

— **Offer Price** α_m **($)** , the insurance premium to be paid to *m* (in amortized or lump-sum form) if SC_m is cleared;

— **Exercise Set** $\mathbb{T}_m^{\mathrm{ex}}$ giving all times between the close of market M(T) and the start of operating period T when the RTO/ISO can exercise SC_m ;

— **Power-Path Production Possibility Set** $\mathbf{PP}_m$, a digital twin characterization of the *power-path production capabilities* that *m* is offering for possible dispatch during T;

— **Performance Payment Method** φ_m , a function mapping each power-path **p** in $\mathbf{PP}_m$ into *m*'s required dollar compensation $\varphi_m(\mathbf{p})$ if *m* is dispatched to deliver **p** during T .

Reserve Offers in 2-Part Pricing Swing-Contract Form … *Continued*

Power-Path Production Possibility Set PP$_m$:

— **PP$_m$** characterizes the physical attributes of the power-paths **p$_m$** that *m* is offering in ***advance*** of operating period T for ***possible*** RTO/ISO-dispatched delivery ***during*** T at *m*'s grid location *b(m).*

— **PP$_m$** permits *m* to specify with care the ***"swing"*** (***flexibility***) in the physical attributes of its offered power-paths.

The physical attributes of each power-path p$_m$ in PP$_m$ can include:

Static Attributes: Grid delivery location *b(m)*; grid-delivered energy (MWh) …

Dynamic Attributes: Power *profile* for T; power-factor *profile* for T; ramp-rate *profile* for T; down-time/up-time *profile* for T; power-path *length* ("power mileage") for T; …

➡ Grid-delivered energy (MWh) is only one among many potentially valuable power-path attributes that *m* can seek to supply in return for appropriate compensation through submission of a swing-contract reserve offer.

Two-Part Pricing Form of Swing Contracts Permits Assured Revenue Sufficiency:

[Revenue] ≥ [Avoidable Cost] =: [Avoidable Fixed Cost + Variable Cost]

Offer Price: α_m (measured in $)

— α_m permits supplier *m* to receive compensation *ex ante* (i.e., before T) for any *avoidable fixed cost* that *m* must incur to guarantee the *advance availability* of the power-paths **p** in $\mathbf{PP}_m$ for *possible* RTO/ISO dispatch at *m*'s grid location *b(m)* during T.

Avoidable Fixed-Cost Examples: Ref. [1, Appendix A.4]

Capital investment cost; Transaction cost (insurance, licensing,…); Unit commitment cost; Opportunity cost; …

Performance Payment Method: $\mathbf{p} \mapsto \varphi_m(\mathbf{p})$ (measured in $)

— φ_m permits supplier *m* to receive compensation *ex post* (i.e., after T) for any *variable cost* $\varphi_m(\mathbf{p'})$ that *m* incurs for *verified* actual *period-T delivery of a power-path* **p'** in $\mathbf{PP}_m$ in accordance with RTO/ISO dispatch instructions (set-points) received during T.

Variable Cost Examples: Ref. [1, Appendix A.4]

Fuel cost; Labor cost; Equipment wear & tear due to ramping; Transmission service charges; …

Two-Part Pricing Swing-Contract Reserve Offers … *Continued*

- The performance payment method φ_m should ideally be expressed in terms of **standardized performance metrics**.

- These metrics **should permit the RTO/ISO and *m*:**
  - — to agree *ex ante* (i.e., *in advance of T*) on the nature of the power-path production *capabilities* that *m* is offering for *possible* RTO/ISO-dispatched delivery *during* T;
  - — to verify *ex post* (i.e., *after T*) the extent to which any *actual* delivery by *m* of a power-path during T deviates from admissible dispatch set-points that the RTO/ISO has communicated to *m* during T .

Example:

Determine performance cost $\varphi_m(\mathbf{p})$ of each power-path **p** in $\mathbf{PP}_m$ as a **linear combination of metrics** that assign costs to various correlated ("jointly produced") physical attributes of **p**, such as **grid-delivered energy (*E*)**, **ramp (*R*)**, and **duration (*D*)**.

$$\varphi_m(\mathbf{p}) \;=\; \underbrace{c^E(\mathbf{p}) \;+\; c^R(\mathbf{p}) \;+\; c^D(\mathbf{p}) \;+\; \ldots}$$

Costs assigned to correlated physical attributes of a single power-path **p**

Swing Contract Illustrative Examples *SC Book, Ref. [2, Chapter 5]*

Example 1: *A simple energy-block swing contract in firm form*

Note: As shown in **Ref. [2]**, this type of swing contract can easily be modified to implement current types of supply offers, such as ***ERCOT's three-part supply offer.***

$$\boxed{\mathrm{SC}_m = [\alpha,\ \mathbb{PP},\ \phi]}$$

where:

$\alpha = \text{Offer price}$

$\mathbb{PP} = (b, t^{\mathsf{s}}, p^{\mathsf{disp}}, t^{\mathsf{e}})$

$b = \text{Delivery location}$

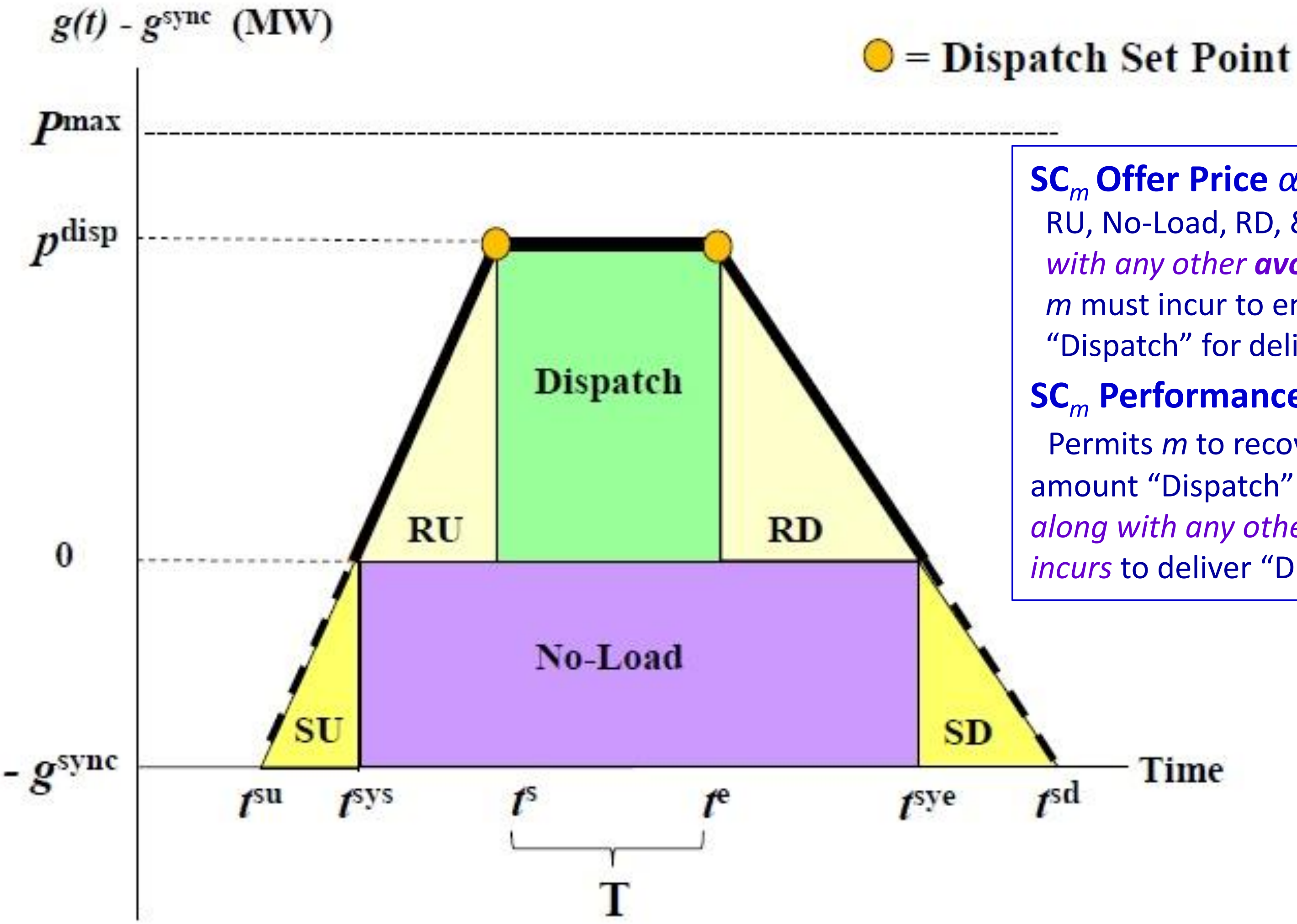
$t^{\mathsf{s}} = \text{Start time for energy block E}$

$p^{\mathsf{disp}} = \text{Maintained power injection for energy block E}$

$t^{\mathsf{e}} = \text{End-time for energy block E}$

$\phi = \text{Pre-specified price } \pi \text{ for delivered energy}$

Example 1: *A simple energy-block swing contract … Continued*



SC_m Offer Price α: Permits *m* to cover SU, RU, No-Load, RD, & SD energy costs *along with any other* ***avoidable fixed*** *cost* that *m* must incur to ensure the availability of "Dispatch" for delivery at *b(m)* during T.

SC_m Performance Payment Method φ: Permits *m* to recover the cost of the energy amount "Dispatch" delivered at *b(m)* during T *along with any other* ***variable*** *cost that m incurs* to deliver "Dispatch" at *b(m)* during T.

Fig. 4 *Illustration of m's* ***energy*** *requirements for delivery of energy-block "Dispatch" at m's grid-location b(m) during operating period T: namely, the energy-block ("Dispatch"); start-up ("SU"); ramp-up ("RU"); no-load ("No-Load"), ramp-down ("RD"), and shut-down ("SD").*

Example 2: *A piecewise-linear swing contract in firm form*

$$\boxed{\mathrm{SC}_m = [\alpha, \mathbb{PP}, \phi]}$$

where:

α = Offer price

$\mathbb{PP} = (b, t^{\mathrm{s}}, p^{\mathrm{s}}, \mathbb{RR}(\mathrm{R1}), t^{\mathrm{E1}}, \mathbb{P}(\mathrm{E1}), t^{\mathrm{R2}}, \mathbb{RR}(\mathrm{R2}), t^{\mathrm{E2}}, \mathbb{P}(\mathrm{E2}), t^{\mathrm{e}})$

b = Delivery location

t^{s} = Start-time for ramp interval R1

p^{s} = Power injection level at start-time t^{s}

$\mathbb{RR}(\mathrm{R1})$ = Set of feasible ramp-rates $r(p^{\mathrm{s}},p_i(\mathrm{E1}))$ for R1

t^{E1} = Start-time for energy block E1

$\mathbb{P}(\mathrm{E1})$ = Set of feasible maintained power-steps $p_i(\mathrm{E1})$ for E1

t^{R2} = Start-time for ramp interval R2

$\mathbb{RR}(\mathrm{R2})$ = Set of feasible ramp-rates $r(p_i(\mathrm{E1}),p_j(\mathrm{E2}))$ for R2

t^{E2} = Start-time for energy block E2

$\mathbb{P}(\mathrm{E2})$ = Set of feasible maintained power-steps $p_j(\mathrm{E2})$ for E2

t^{e} = End-time for E2

ϕ = Payment for ramp and delivered energy calculated by means of power-path mileage and a pre-specified price $\pi(p)$ for each $p \in \mathbb{P}(\mathrm{E1}) \cup \mathbb{P}(\mathrm{E2})$

Example 2: *A piecewise-linear swing contract … Continued*

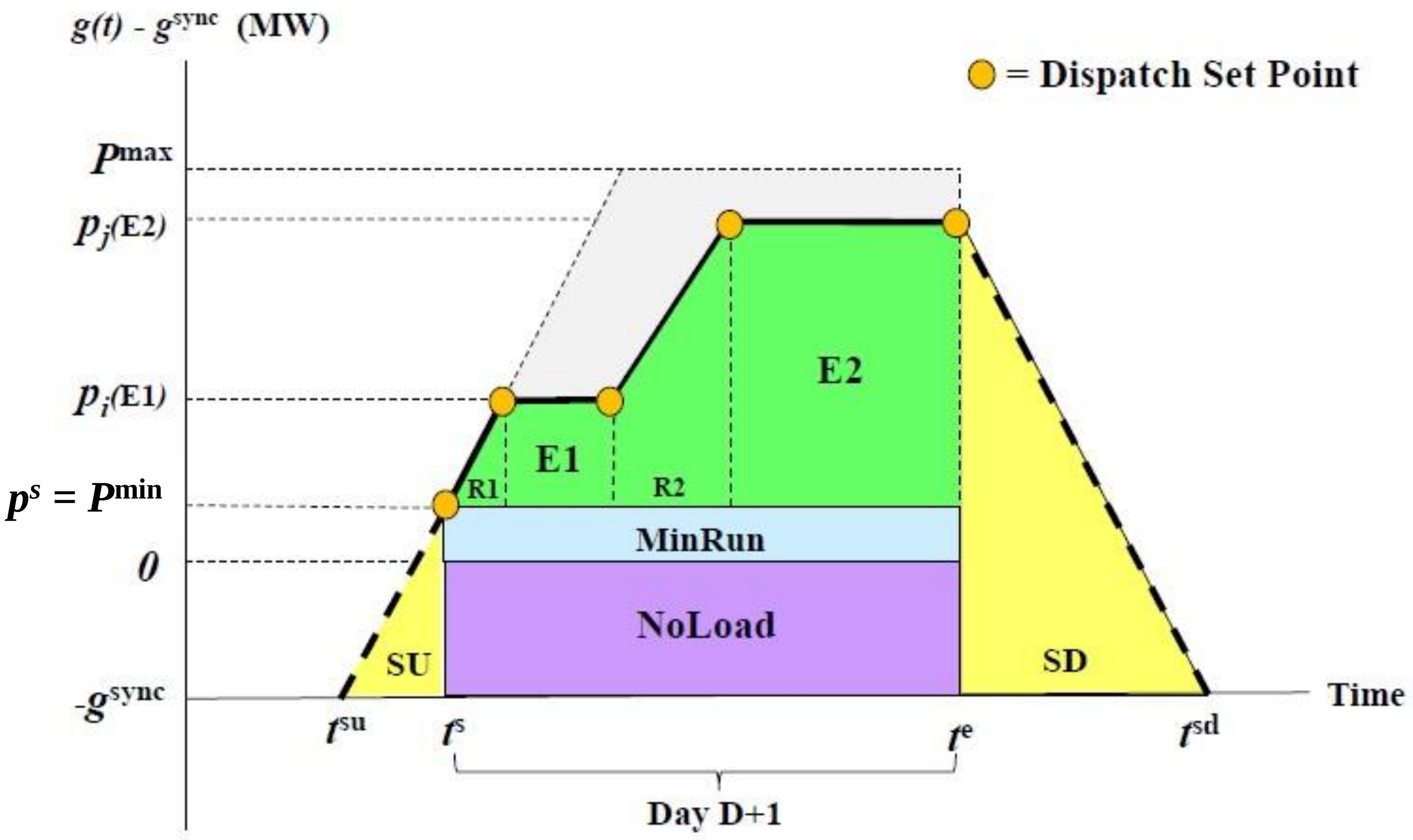


Fig. 5: ***One among multiple possible power-paths p*** *the RTO/ISO could dispatch m to deliver at m's grid-location b(m) during operating day D+1 if the RTO/ISO clears m's piecewise-linear swing-contract* SC_m *submitted to a swing-contract day-ahead market M(D+1) held on day D.*

Example 3: *A swing contract in firm form offering battery charge/discharge as an ancillary service*

$$\boxed{\mathrm{SC}_m = [\alpha, \mathbb{PP}, \phi]}$$

where:

α = Offer price

$\mathbb{PP} = (b, ECap^{\mathrm{max}}, \eta, t^{\mathrm{s}}, \mathbb{SOC}^{\mathrm{s}}, \mathbb{RR}, \mathbb{P}, t^{\mathrm{e}}, \mathbb{SOC}^{\mathrm{e}})$

- b = Delivery location
- $ECap^{\mathrm{max}}$ = Maximum energy storage capacity
- η = Round-trip efficiency
- t^{s} = Start-time for power discharge/charge
- $\mathbb{SOC}^{\mathrm{s}}$ = Set of feasible state-of-charge percentages at t^{s}
- $\mathbb{P} = [P^{\mathrm{min}}, P^{\mathrm{max}}]$ = Range of feasible discharge/charge levels p
- $\mathbb{RR} = [-R^{\mathrm{D}}, R^{\mathrm{U}}]$ = Range of feasible ramp-rates r
- t^{e} = End-time for power discharge/charge
- $\mathbb{SOC}^{\mathrm{e}}$ = Set of feasible state-of-charge percentages at t^{e}

ϕ = Performance payment method for down/up power-path delivery

Example 3: *Swing contract in firm form offering battery service… Continued*

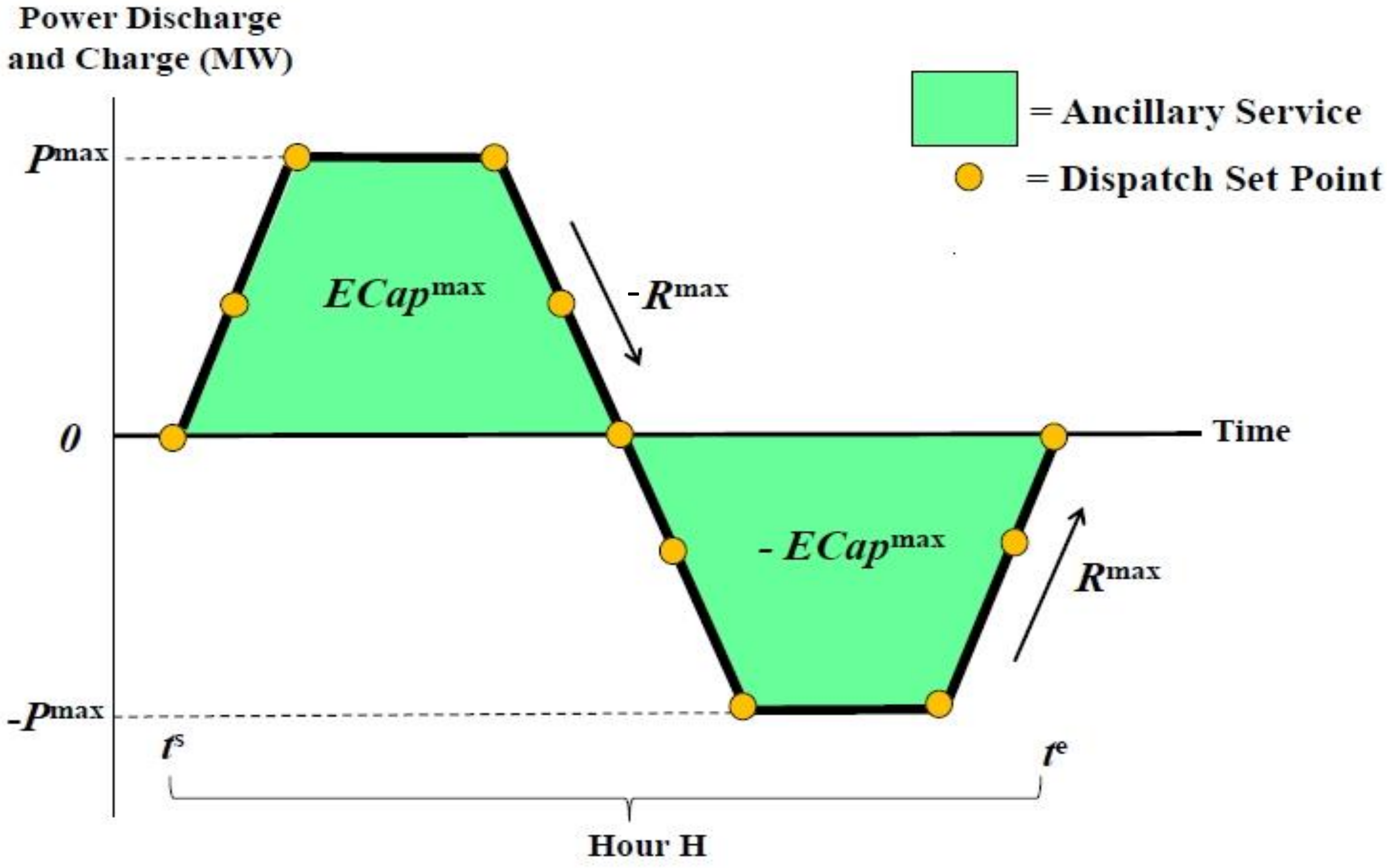


Fig. 6: *Suppose* **SOC^s = SOC^e** *= {**100%**},* ***P^{min} = - P^{max}****, and $R^D = R^U =: R^{max}$. Then the depicted dispatched power-path is **one among multiple power-paths p** the RTO/ISO could dispatch m to deliver at m's grid-location b(m) during hour H = [t^s, t^e) if the RTO/ISO clears m's battery service swing-contract SC_m submitted to a swing-contract market M(H) held in advance of H.*

Example 4: *Swing contract (firm) with flexible power & ramp*

Note: Proposed for Integrated T&D support (FERC Order No. 2222) in **Ref. [2**, Ch. 5**]**

$$\boxed{\mathrm{SC}_m = [\alpha, \mathbb{PP}, \phi]}$$

where:

$$\alpha = \text{Offer price}$$

$$\mathbb{PP} = (b, t^{\mathsf{s}}, p^{\mathsf{s}}, \mathbb{P}, \mathbb{RR}, t^{\mathsf{e}})$$

$$b = \text{Delivery location}$$

$$t^{\mathsf{s}} = \text{Start-time for power delivery}$$

$$p^{\mathsf{s}} = \text{Initial power level at time } t^{\mathsf{s}}$$

$$\mathbb{P} = [P^{\mathsf{min}}, P^{\mathsf{max}}] = \text{Range of feasible down/up power levels } p$$

$$\mathbb{RR} = [-R^{\mathsf{D}}, R^{\mathsf{U}}] = \text{Range of feasible down/up ramp-rates } r$$

$$t^{\mathsf{e}} = \text{End-time for power delivery}$$

$$\phi = \text{Performance payment method for power-path delivery}$$

Example 4: *Swing contract (firm) with flexible power & ramp … Continued*

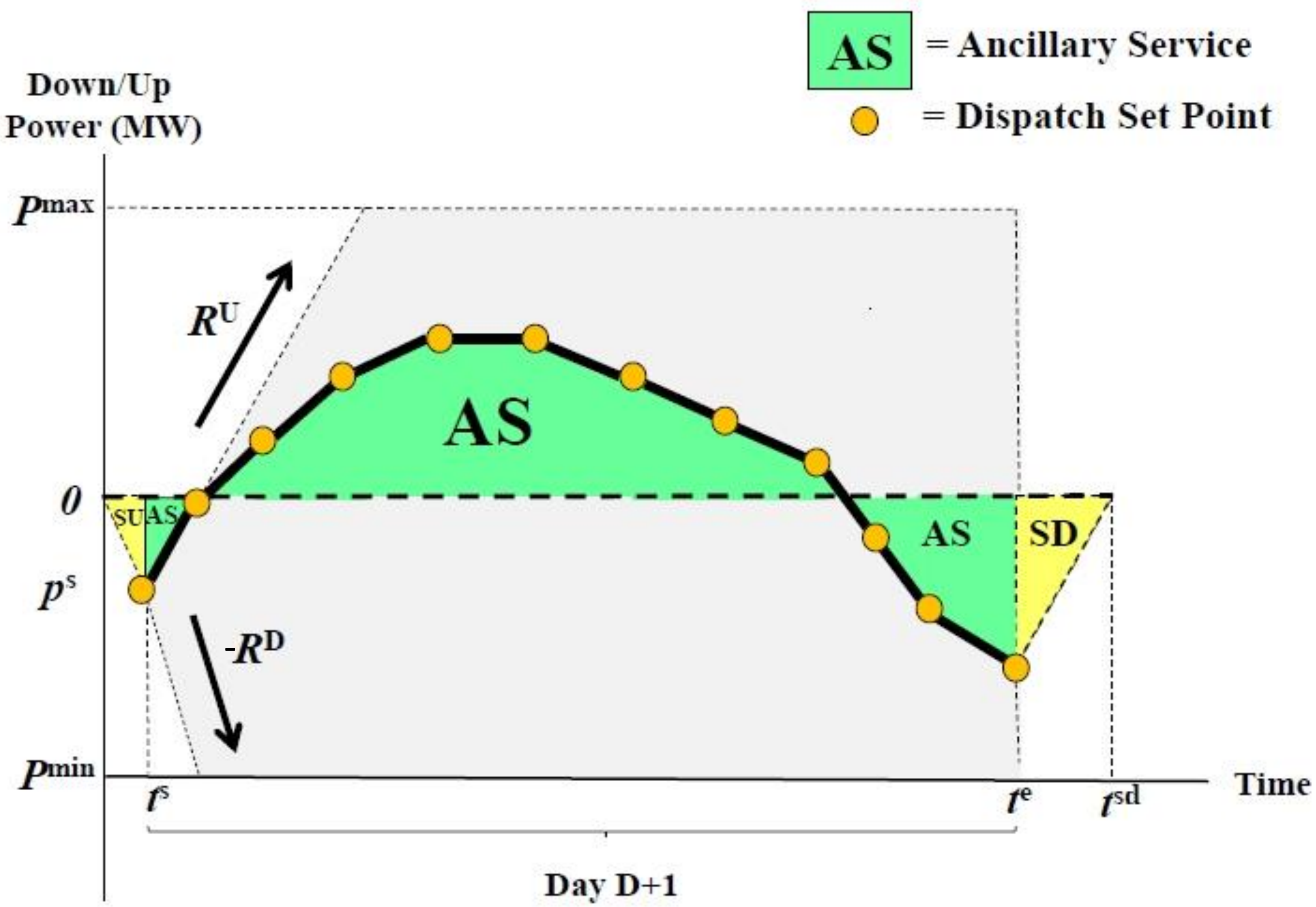


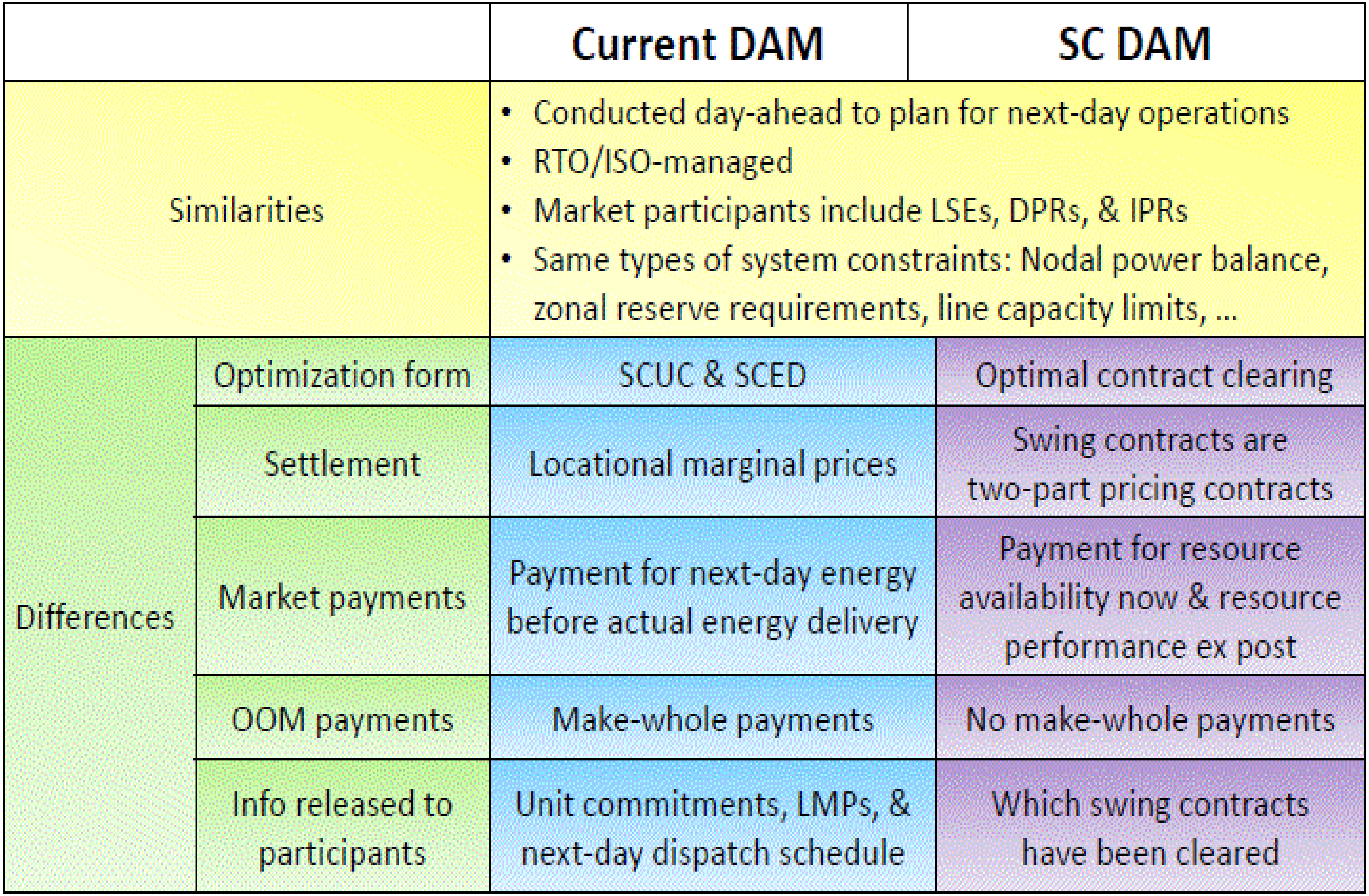
Fig. 7: ***One among many possible power-paths p*** *the RTO/ISO could dispatch m to deliver at m's grid-location b(m) during operating day D+1 if the RTO/ISO clears m's flexible power/ramp swing-contract* SC_m *submitted to a swing-contract day-ahead market M(D+1) held on day D.*

Comparisons: SC Market Design **vs.** Current Design of U.S. RTO/ISO-Managed Wholesale Power Markets

- **Detailed comparisons** of key design features and performance capabilities (with illustrative 5-118 bus test-case outcomes) for the Linked Swing-Contract Market Design and the design of current U.S. RTO/ISO-managed wholesale power markets are provided in **Refs. [1-4]** listed at the end of this presentation.

- **Illustrative comparisons** of key design features and optimization formulations for current and SC-proposed **D**ay-**A**head **M**arkets (**DAM**s) are provided in tables on the next two slides.

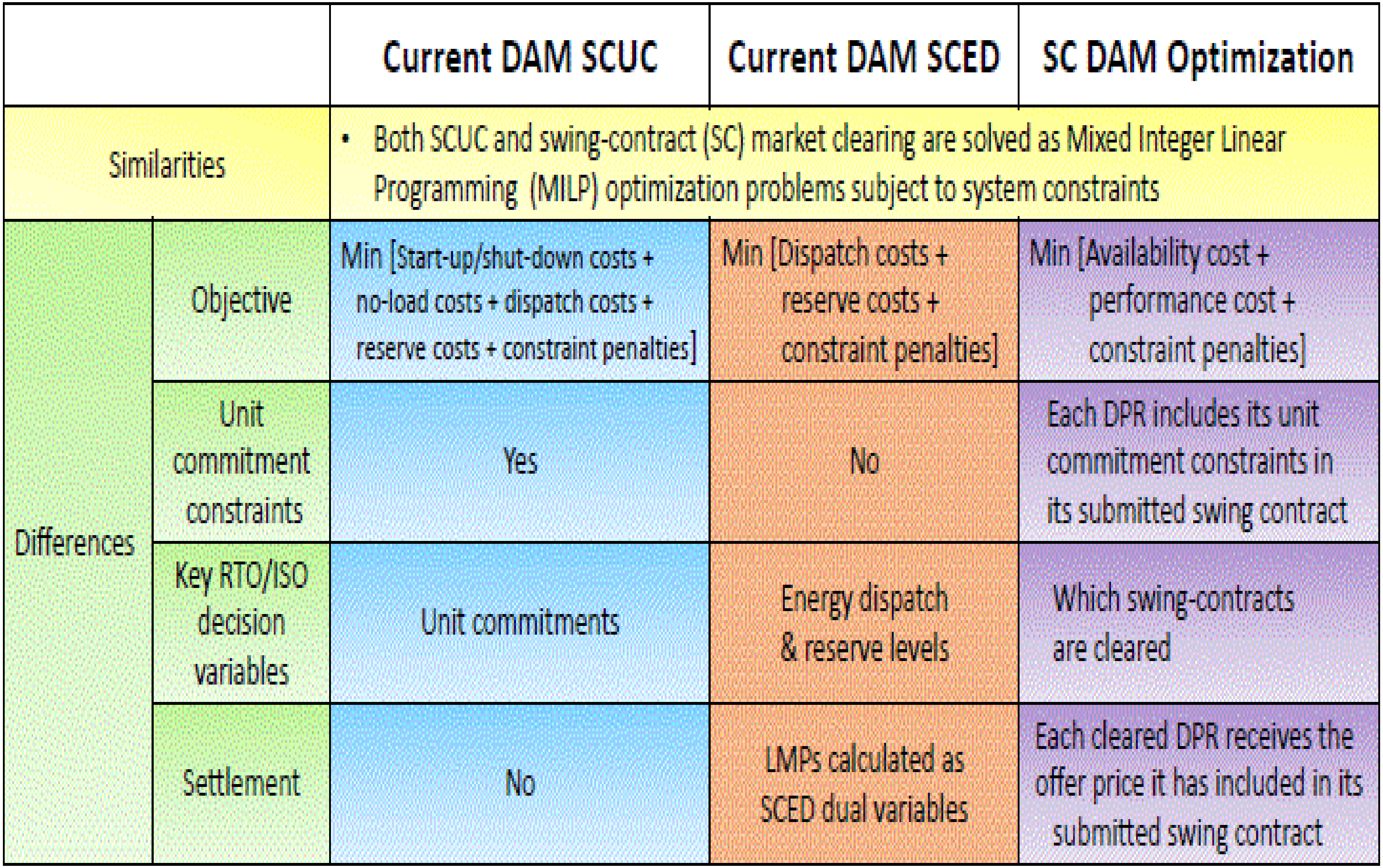
DAM Design Comparisons: Key Features



		Current DAM	SC DAM
Similarities		• Conducted day-ahead to plan for next-day operations • RTO/ISO-managed • Market participants include LSEs, DPRs, & IPRs • Same types of system constraints: Nodal power balance, zonal reserve requirements, line capacity limits, …	
Differences	Optimization form	SCUC & SCED	Optimal contract clearing
	Settlement	Locational marginal prices	Swing contracts are two-part pricing contracts
	Market payments	Payment for next-day energy before actual energy delivery	Payment for resource availability now & resource performance ex post
	OOM payments	Make-whole payments	No make-whole payments
	Info released to participants	Unit commitments, LMPs, & next-day dispatch schedule	Which swing contracts have been cleared

LSE =: Load Serving Entity; IPR =: Intermittent Power Resource; DPR =: Dispatchable Power Resource

DAM Design Comparisons: Optimization Formulations



		Current DAM SCUC	Current DAM SCED	SC DAM Optimization
Similarities		• Both SCUC and swing-contract (SC) market clearing are solved as Mixed Integer Linear Programming (MILP) optimization problems subject to system constraints		
Differences	Objective	Min [Start-up/shut-down costs + no-load costs + dispatch costs + reserve costs + constraint penalties]	Min [Dispatch costs + reserve costs + constraint penalties]	Min [Availability cost + performance cost + constraint penalties]
	Unit commitment constraints	Yes	No	Each DPR includes its unit commitment constraints in its submitted swing contract
	Key RTO/ISO decision variables	Unit commitments	Energy dispatch & reserve levels	Which swing-contracts are cleared
	Settlement	No	LMPs calculated as SCED dual variables	Each cleared DPR receives the offer price it has included in its submitted swing contract

DPR =: Dispatchable Power Resource

Conclusion

- ☐ U.S. RTO/ISO-managed wholesale power markets are currently attempting to decarbonize their grid operations and to diversify their market participants.
- ☐ This presentation first identified three conceptually-problematic design aspects of these markets that are hindering these attempts:
  - — Product definition and pricing issues;
  - — Settlement-timing issues;
  - — Supply-offer formulation issues.
- ☐ The Linked Swing-Contract Market Design – an alternative RTO/ISO-managed wholesale power market design developed and tested at Technology Readiness Level TRL-3 in **Refs. [2-4]** -- was then briefly reviewed.
- ☐ This alternative SC design appears well-suited for the support of decarbonized grid operations with diverse market participants.
- ☐ Adoption of this alternative SC design would require changes in product definitions, settlement rules, and supply-offer forms, but *not* in real-time operations.
- ☐ Thus, as explained and illustrated in **Ref. [2, Ch. 16]** and **Ref. [4]**, adoption of this alternative SC design could proceed by gradual transition without disruption of real-time operations.

References

Ref. [1] Leigh Tesfatsion (2023), **Economics of Grid-Supported Electric Power Markets: A Fundamental Reconsideration,** Supporting Doc for Comments (Accession #20230117-5051, 65pp.) e-filed by L. Tesfatsion to U.S. Federal Energy Regulatory Commission for Docket #AD21-10-000 ("Modernizing Wholesale Electricity Market Design").
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Ref. [2] Leigh Tesfatsion (2021), **A New Swing-Contract Design for Wholesale Power Markets**, 20 Chpts, 288pp., John Wiley & Sons (IEEE Press Series on Power Engineering), Hoboken, NJ.
https://www2.econ.iastate.edu/tesfatsi/SCBookReview.IEEEPESMag2022.pdf
https://www2.econ.iastate.edu/tesfatsi/ANewSwingContractDesign.Flyer.WileyIEEEPress.pdf

Ref. [3] Leigh Tesfatsion (2023), **"Locational Marginal Pricing: When and Why Not?,"** Working Paper #23003, ISU Digital Repository, Iowa State University, Ames, IA.
https://www2.econ.iastate.edu/tesfatsi/LMPWhenAndWhyNot.LTesfatsion.pdf

Ref. [4] Wanning Li and Qi Wang (2023), **"A Linked Swing Contract Market Design with High Renewable Penetration and Battery Firming,"** *IEEE Transactions on Power Systems,* to appear. doi: 10.1109/TPWRS.2023.3274734. IEEE Early Access Preprint available at:
https://ieeexplore.ieee.org/document/10122700