A New Swing-Contract Design for Wholesale Power Markets

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Presentation Outline

- ❑ Swing-Contract Market Design: Overview

- ❑ Optimal Market Clearing Formulation

- ❑ Support for Increased DER Participation: FERC Order 2222

- ❑ Conclusion

Key Reference:

[1] Leigh Tesfatsion, A New Swing-Contract Design for Wholesale Power Markets, Wiley (IEEE Press Series on Power Engineering), 20 Chapters, 288pp., ©2021.
http://www2.econ.iastate.edu/tesfatsi/ANewSwingContractMarketDesign.Flyer.WileyIEEEPress.pdf

Swing-Contract Market Design: Overview

- Ref. [1] develops a linked swing-contract market design for centrally-managed wholesale power markets to facilitate increased participation by distributed energy resources (DERs) and end-use customers.

— A *swing-contract market M(T) for a future operating period T* is an ISO-managed forward reserve market for T, where reserve consists of dispatchable "power-paths" for T.

— A *power-path for a time interval T* is a flow of power injections and/or withdrawals (MW) at a single grid location during T.

Power-Path Illustration

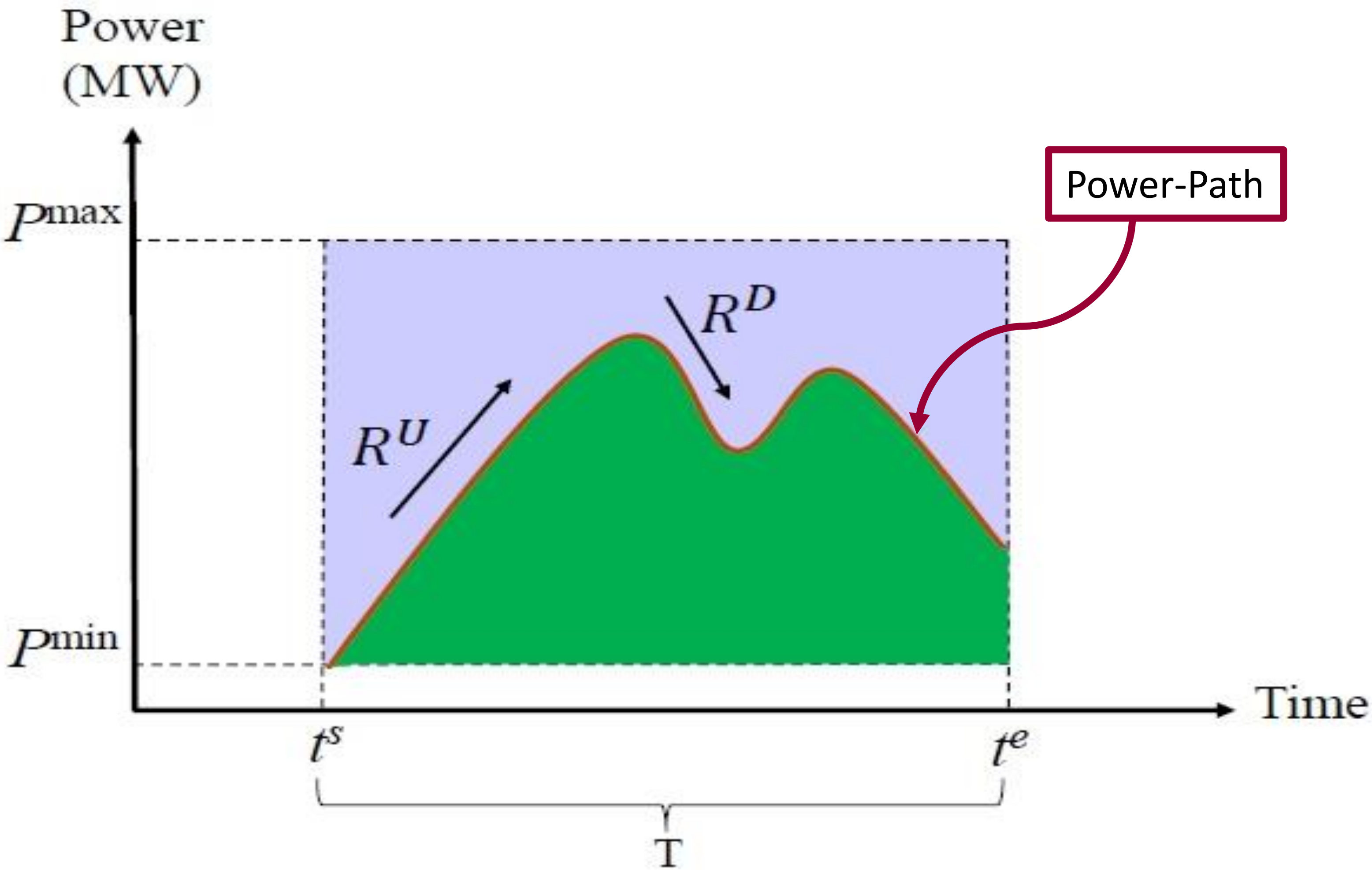
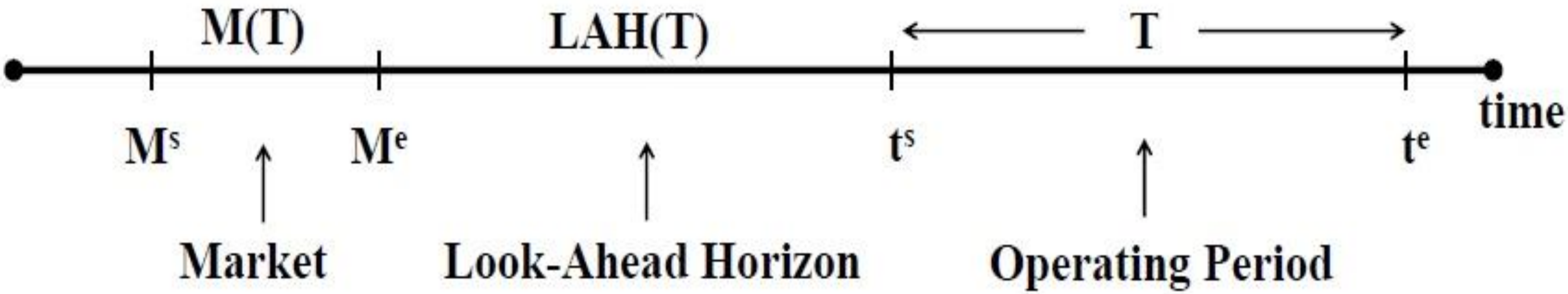


Fig. 1: *One of many possible power-paths that a dispatchable resource with swing (flexibility) in power amplitude & down/up ramping could deliver at its grid location during an operating period T in response to ISO dispatch instructions.*

Bids/Offers for a Swing-Contract Market M(T)



- A *reserve bid* submitted to M(T) is a price-sensitive or fixed demand for power-path delivery during T.

- A *reserve offer* submitted to M(T) is a swing contract that offers the availability of power-paths for possible ISO-dispatched delivery during T.

Swing-Contract: General Analytical Formulation

- A *swing contract*

$$\mathrm{SC}_m = (\alpha_m, \mathrm{T}_m^{\mathrm{ex}}, \mathrm{PP}_m, \varphi_m)$$

offered by a dispatchable resource *m* into an ISO-managed SC market M(T) for a future operating period T consists of:

- an *offer price* α_m;
- an *exercise set* $\mathrm{T}_m^{\mathrm{ex}}$ of possible contract exercise times;
- a *physically characterized set* PP_m *of power-paths for T*, each of which *m* could deliver at a designated grid location during T in response to ISO dispatch signals;
- a *performance payment method* φ_m.

Facilitates Compensation for Flexibility

- The offered power-path set PP_m permits dispatchable resource *m*:
  - to specify with care the *swing (flexibility)* in the attributes of its offered power-paths.

- These attributes can include:
  - *static aspects*:
    delivery time; delivery place; amount of delivered energy (MWh); …
  - *dynamic aspects:*
    ramp-rate flexibility; power amplitude flexibility; down-time/up-time duration limits; power mileage; power factor relations (PQ curve) …

Two-Part Pricing

- The *offer price* α_m of the swing contract SC_m
  - permits **coverage ex ante (i.e., before T)** of all avoidable fixed cost incurred to guarantee **reserve availability** for T.

- The *performance payment method* φ_m in SC_m
  - permits **coverage ex post (i.e., after T)** of all variable cost incurred to provide **reserve performance** during T, i.e., the dispatched delivery during T of a power-path in PP_m.
  - permits extension of FERC Order 755 “pay for performance” principle to general types of reserve: *No payment for reserve performance in advance of actual real-time performance.*

EXAMPLE 1: SC_m offers multiple energy blocks at flexibly set power levels, supported by flexible down/up ramping

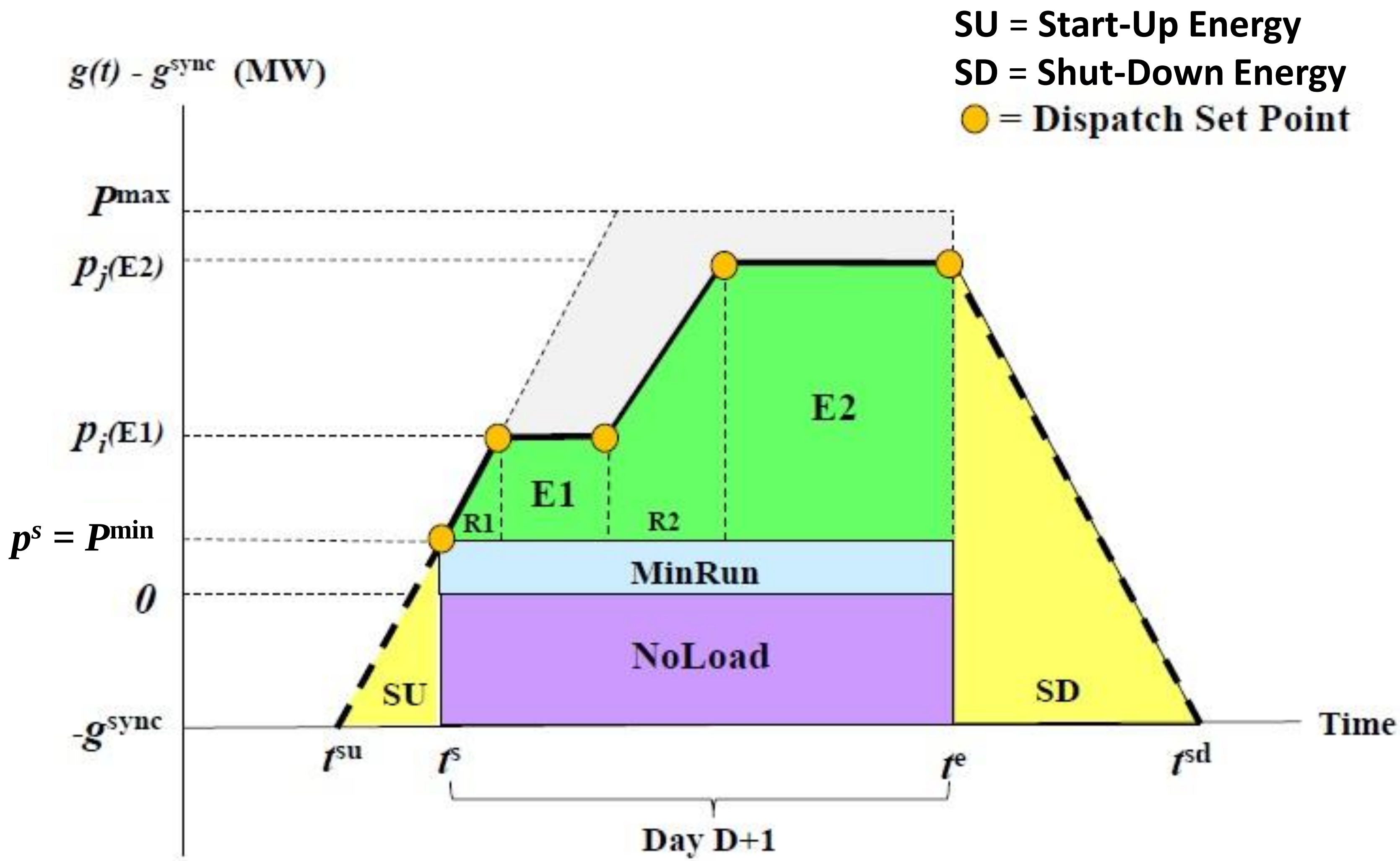


Fig. 2: *One among many possible power-paths the ISO on day D could dispatch m to deliver during day D+1 if the ISO clears m's multi-block SC offer.*

EXAMPLE 2: SC_m offers flexible down/up power & ramp

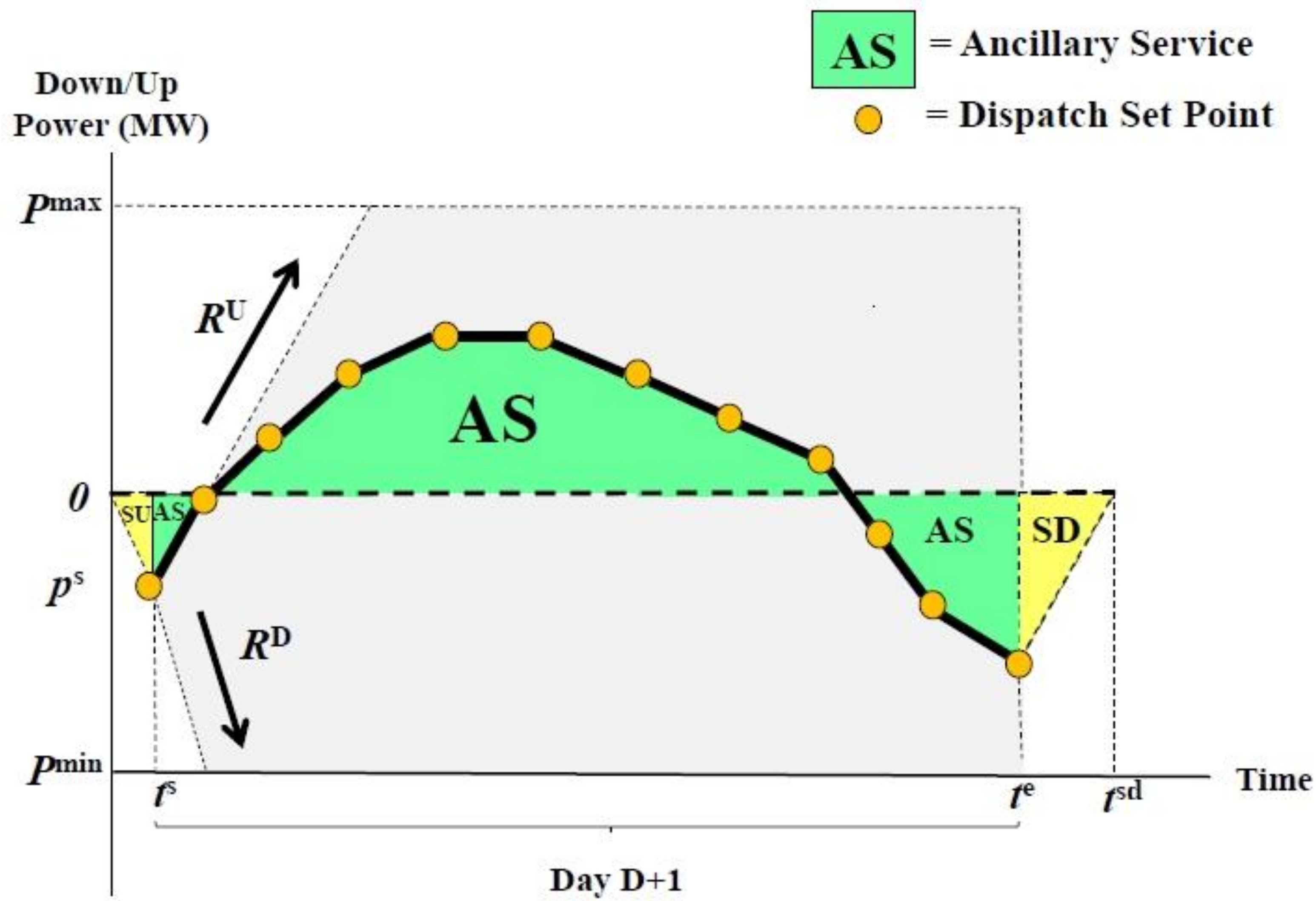


Fig. 3: *One of many possible power-paths the ISO on day D could signal m to deliver during day D+1 if the ISO clears m's SC that offers flexible down/up power & ramp.*

Swing-Contract Market: Optimization

- ISO managing M(T) for a future operating period T solves a contract-clearing optimization problem:
  - Which price-sensitive reserve bids to clear for T ?
  - Which reserve offers to clear for T?

- ISO Objective: Maximize expected total net benefit of M(T) participants.

Total Net Benefit = [Reserve Benefit – Reserve Cost]

Reserve Benefit = [Customer benefit expressed via reserve bids]

Reserve Cost = [Offer Cost (OC) + Performance Cost (PC) + Imbalance Cost (IC)]

❑ ISO Optimization: Initial Conditions

— Forecasted or calculated down/up-time status and initial power level of each dispatchable resource *m* at the start of operating period T;

— Forecasted fixed load at each bus during T;

— Forecasted non-dispatchable generation at each bus during T.

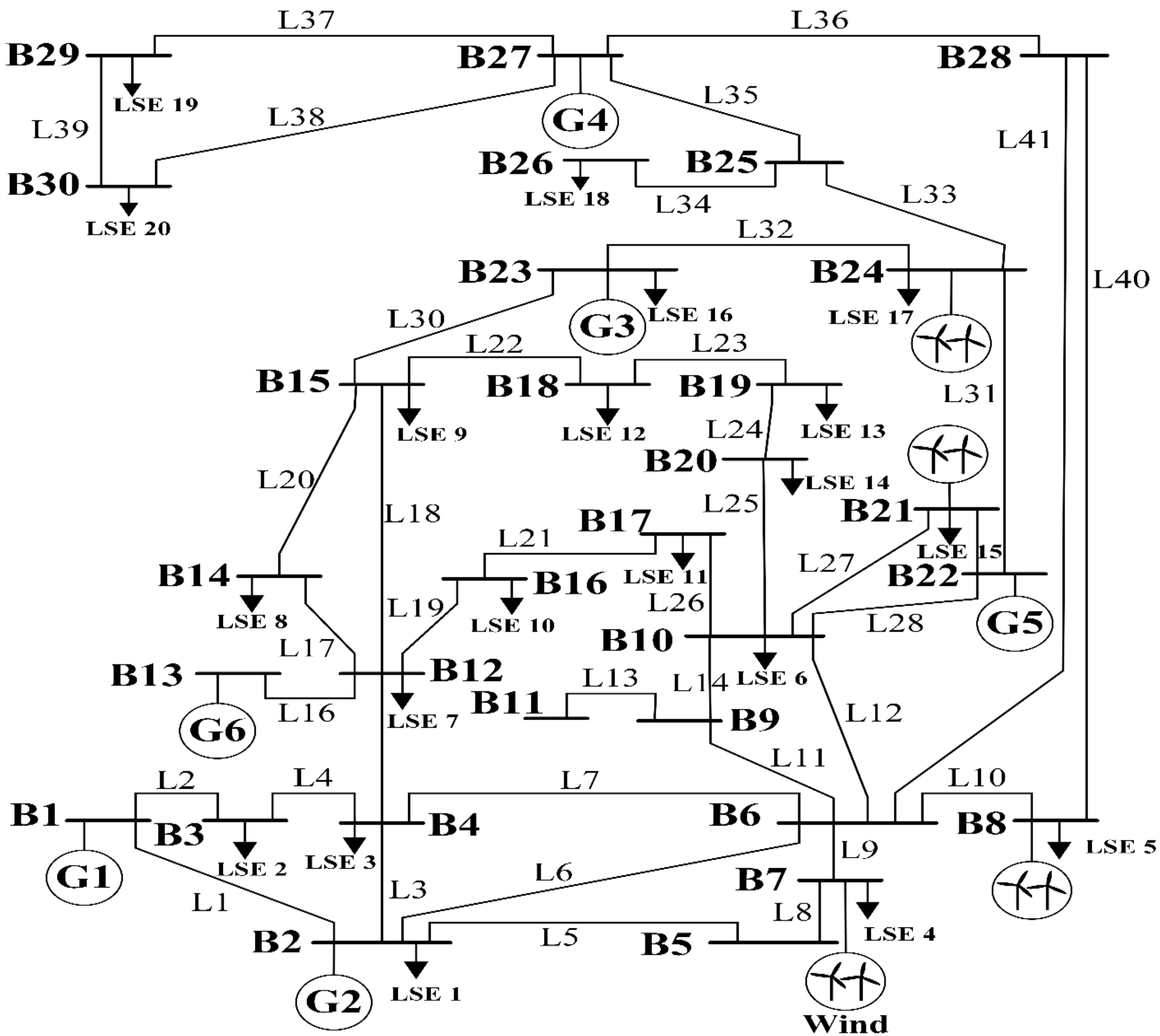
ISO Optimization: System constraints

Note: The system constraints incorporate initial conditions plus power-path attributes extracted from submitted swing contracts

- transmission line constraints;
- power balance constraints (with slack variables);
- dispatchable resource capacity constraints;
- dispatchable resource ramping constraints (start-up, normal, & shut-down);
- dispatchable resource minimum up-time/down-time constraints;
- dispatchable resource hot-start constraints;
- dispatchable resource start-up/shut-down cost constraints;
- system-wide and zonal down/up reserve requirement constraints;
- bus voltage angle constraints.

Illustration: An SC DAM 30-Bus Test Case with Fixed Loads

[2] Shanshan Ma, Zhaoyu Wang, and Leigh Tesfatsion (2019), "Swing Contracts with Dynamic Reserves for Flexible Service Management," *IEEE Trans. on Power Systems*, 34(5), 4024-4037.



ISO Optimization Problem for Test Case

NOTE: Operating period T is discretized into time-steps k to obtain a standard MILP form.

ISO Objective:

Select decision variables to minimize forecasted total avoidable cost, subject to system constraints, where forecasted total avoidable cost is given by:

$$\widehat{\mathrm{C}}(T) = \underbrace{\sum_{m\in\mathbb{M}} [\underbrace{c_m\alpha_m}_{\text{Offer Cost}} + \underbrace{\phi_m(\mathbf{p}_m)}_{\text{Perf. Cost}}]}_{\text{OC + PC}} + \underbrace{\sum_{b\in\mathbb{B}}\sum_{k\in\mathbb{K}} \underbrace{[\Lambda^-\beta_b^-(k) + \Lambda^+\beta_b^+(k)]\Delta t}_{\text{Imbalance Cost}}}_{\text{IC}}$$

ISO Binary Decision Variables:

- Contract clearing indicators: $c_m \in \{0,1\}$, $\forall m \in \mathbb{M}$

ISO Continuously-Valued Decision Variables:

- Power dispatch levels: $p_m(k)$, $\forall m \in \mathbb{M}$, $k \in \mathbb{K}$
- Bus voltage angles: $\theta_b(k)$, $\forall b \in \mathbb{B}/\{1\}$, $k \in \mathbb{K}$

Variables Determined by ISO Decisions and System Constraints:

- Run-time minimum power levels: $\underline{p}_m(k)$, $\forall m \in \mathbb{M}$, $k \in \mathbb{K}$
- Run-time maximum power levels: $\overline{p}_m(k)$, $\forall m \in \mathbb{M}$, $k \in \mathbb{K}$
- Unit availability indicators: $v_m(k) \in \{0,1\}$, $\forall m \in \mathbb{M}$, $k \in \mathbb{K}$
- Transmission line power flows: $w_\ell(k)$, $\forall \ell \in \mathbb{L}$, $k \in \mathbb{K}$
- Power balance slack variables: $\beta_b(k), \beta_b^-(k), \beta_b^+(k)$, $\forall b \in \mathbb{B}$, $k \in \mathbb{K}$
- Bus voltage angle for reference bus 1: $\theta_1(k)$, $\forall k \in \mathbb{K}$

Test Case Cost Outcomes (OC, PC, IC)

Table 6.6 Thirty-bus SC DAM performance over three successive days for two different reserve zone treatments

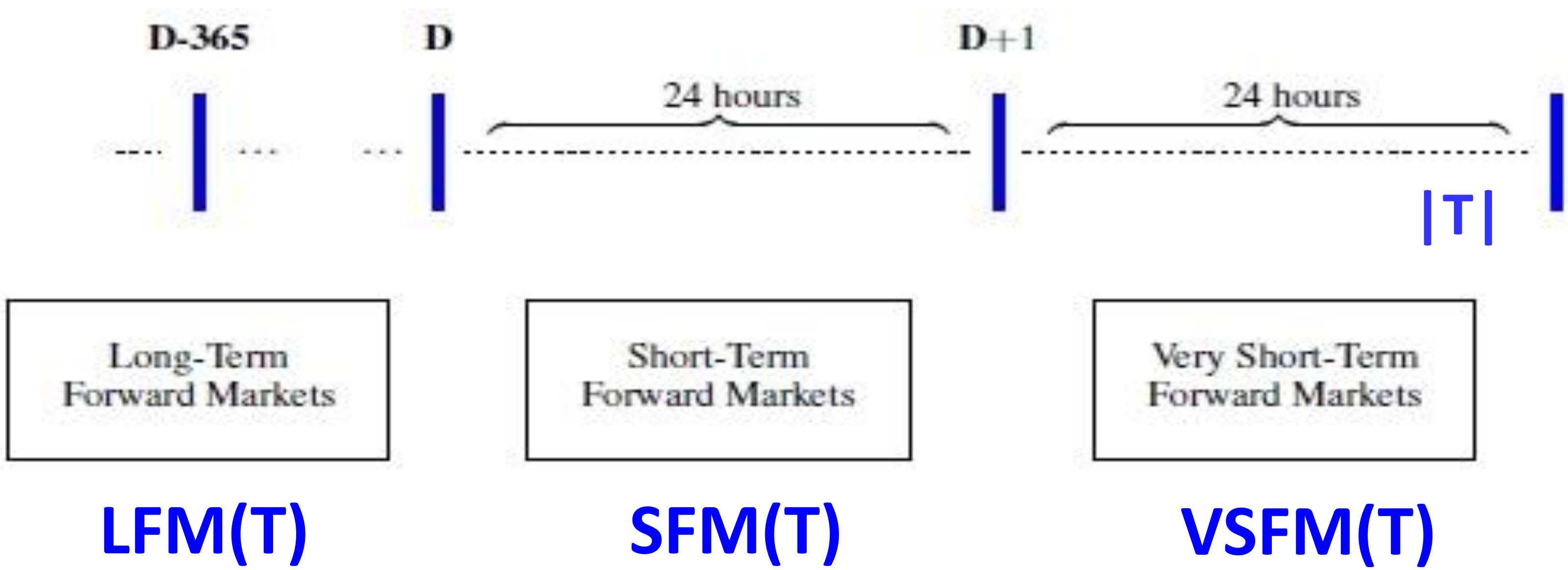
Day D_j	Treatment	Reserve Zones zj	Contract Clearing $c_{G1}, c_{G2}, c_{G3}, c_{G4}, c_{G5}, c_{G6}$	$OC(Z,D_j)$	$E^{xp}[PC(Z,D_j)]$	$E^{xp}[IC(Z,D_j)]$
D_0	Proposed	$z1$: Bus 23 $z2$: Bus 27 29 30 $z3$: Bus 1-22 24 25 26 28	[1,1,1,1,1,1]	\$10,750	\$100,555.65	\$194.22
	Single Zone	$z1$: Bus 1-30	[1,1,1,1,0,1]	\$8,750	\$106,420.12	\$5,371.73
D_1	Proposed	$z1$: Bus 23 $z2$: Bus 21 22 24-27 29 30 $z3$: Bus 1-20 28	[1,1,1,1,1,1]	\$10,700	\$98,012.73	\$10,359.74
	Single Zone	$z1$: Bus 1-30	[1,1,1,1,0,1]	\$9,100	\$99,996.96	\$13,990.73
D_2	Proposed	$z1$: Bus 23 24 25 26 $z2$: Bus 27 29 30 $z3$: Bus 1-22 28	[1,1,1,1,1,1]	\$9,410	\$104,494.04	\$10,597.97
	Single Zone	$z1$: Bus 1-30	[1,1,1,1,0,1]	\$7,810	\$105,077.11	\$13,282.30

Swing-Contract Market … Linkage

- *Linkage is established* among successive SC markets M(T) for a given future operating period T by *ISOPort(T)* = *ISO portfolio of reserve bids/offers cleared for T* that the ISO carries forward through time.

- ISOPort(T) is *updated* by ISO in successive SC markets held prior to T.

EXAMPLE: Successive swing-contract markets M(T) for a future operating period T with look-ahead horizons that range from long-term to very short term.



Support for FERC Order 2222 (Final Rule 9/17/2020)

- Swing contracts can facilitate participation of *Independent Distribution System Operators (IDSOs)* in wholesale power markets as providers of power and/or ancillary services harnessed from aggregates of distributed resources.

Example:

— IDSO submits swing contracts offering down/up power and ramp flexibility as ancillary service, as illustrated on Slide 10.

— IDSO harnesses these ancillary services from *Grid-Edge Resources* in return for appropriate compensation.

— *Grid-Edge Resource (GER)* =: Any power resource with a direct connection to the distribution grid (e.g., household, business, PEV, …)

- This topic is covered in chapters 17-18 of my book [1]

An Integrated Transmission and Distribution (ITD) System with IDSO Linkage Agents

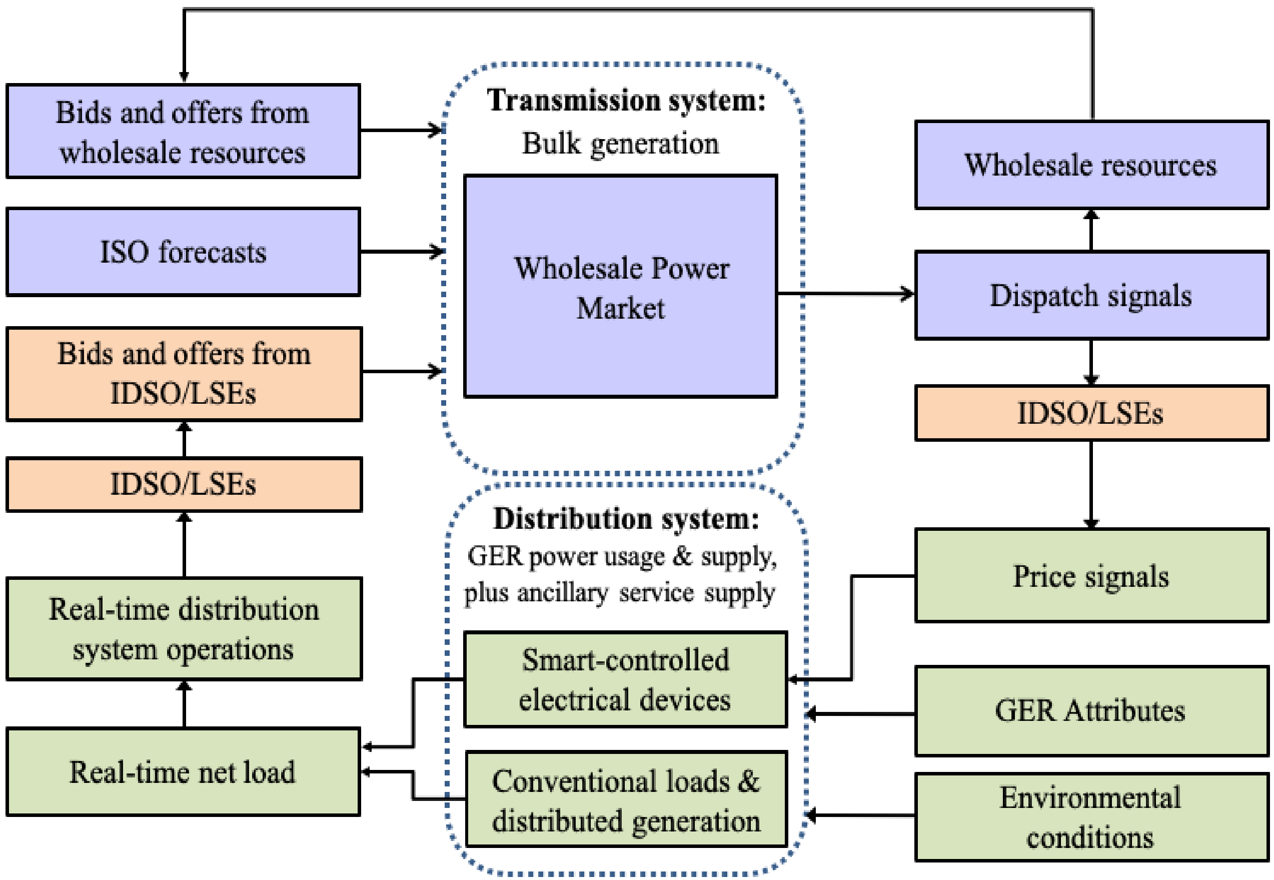


Fig. 4: *An ITD System with IDSO linkage agents, implemented by the ITD TES Platform V2.0.*

See: ITD Project Homepage, **http://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm**

Conclusion

- Purpose of Linked Swing-Contract Market Design
  - facilitate balancing of increasingly volatile & uncertain net load in centrally-managed wholesale power markets.

- Four novel design aspects have been stressed
  - Each swing-contract market is a *forward reserve market;*
  - Reserve is characterized as collections of *power-paths*;
  - Reserve offers are *swing contracts* permitting *flexible reserve provision*
  - *Two-part pricing* form of swing contracts *permits full recovery of availability & performance costs.*

Conclusion … Continued

- Three additional key topics covered in [1]

  - *Reserve bids* expressed via *benefit functions* [1,Ch. 9]

  - *Gradual transition* to linked swing-contract markets: An illustrative transitional day-ahead market [1, Ch. 16]

  - *Option swing contracts* for the provision of *contingency reserve* [1, Ch. 19]

[1] Leigh Tesfatsion, A New Swing-Contract Design for Wholesale Power Markets, Wiley (IEEE Press Series on Power Engineering), 20 Chapters, 288pp., ©2021.
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