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A New Swing-Contract Design for Wholesale Power Markets

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Abstract  The need for flexible dependable reserve provision in electric power systems has dramatically increased in recent years. Growing reliance on variable energy resources and greater encouragement of demand-side participation have led to greater uncertainty and volatility of net load. Consequently, system operators are finding it harder to secure reserve with sufficient flexibility to permit the continual balancing of net load, a basic requirement for power system reliability. This study reconsiders the design of wholesale power markets in light of these concerns. Four design principles are stressed: (i) Wholesale power markets must necessarily be forward markets due to the speed of real-time operations; (ii) Only one type of product can effectively be offered in a wholesale power market: namely, reserve, an insurance product offering availability of net load balancing services for future real-time operations; (iii) Net load balancing services offered into wholesale power markets primarily take the form of power paths that can be dispatched at specific grid locations over time; (iv) All dispatchable resources should be permitted to compete for the provision of power-paths in wholesale power markets without regard for irrelevant underlying technological differences. If these four principles are accepted, current trade and settlement arrangements for wholesale power markets need to be fundamentally altered. This study proposes a new linked swing-contract market design, consistent with principles (i)-(iv), that could meet the needs of centrally-managed wholesale power markets better than currently implemented designs.

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Chapter 1
Introduction

“Design to the mission, design as a system, keep it simple.” [111, p. 20]

Centrally-managed wholesale power markets operating over high-voltage transmission grids support the steady flow of electric power from bulk power sellers to bulk power buyers, for ultimate resale and distribution to retail customers. This mission has been complicated in recent years by a dramatic surge in the availability and use of variable energy resources.

A Variable Energy Resource (VER) is a power source whose power injections into a transmission grid cannot be fully dispatched in a controlled manner to balance changes in power withdrawals or to meet other system requirements. Examples include solar panels and wind turbines that are not fully firmed by storage. The increased participation of VERs in wholesale power markets, together with the increased encouragement of active demand-side participation, increases the uncertainty and volatility of grid net load, i.e., power withdrawal net of non-dispatched power injection.

In consequence, as discussed more fully in Chapters 2–3, U.S. RTO/ISO-managed wholesale power markets\(^1\) are finding it harder to secure dependable reserve with sufficient flexibility to permit the continual balancing of net load, a basic requirement for power system reliability. Trade and settlement arrangements in these markets are still largely based on rigid reserve definitions, eligibility requirements, and settlement processes that make it difficult to ensure adequate provision and appropriate compensation of needed reserve from multiple types of resources. Emphasis is placed on the designation and compensation of artificially-separated product concepts such as energy, ramping, and capacity whereas value in power markets in fact principally arises from the dispatchable availability and delivery of power-paths, i.e., flows of power into and out of a grid at specific grid locations during designated operating periods.

This study reconsiders the design of U.S. RTO/ISO-managed wholesale power markets in light of these concerns. Four market design principles are stressed:

[MD1:] All wholesale power markets must necessarily be forward markets\(^2\) due to the speed of real-time operations.
[MD2:] Only one type of product can effectively be offered in a wholesale power market: namely, reserve, an insurance product offering availability of net load balancing services for future real-time operations.

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\(^1\) The U.S. Federal Energy Regulatory Commission [59] defines an RTO/ISO-managed wholesale power market to be the collection of all capacity, energy, and/or ancillary service markets operated by a Regional Transmission Organization (RTO) or an Independent System Operator (ISO). The key distinction between an RTO and an ISO is that RTOs have larger regional scope.

\(^2\) A forward market is a market involving the purchase and sale of a product for which the payment method for the product is contractually determined in advance of its delivery date. In contrast, in a spot market the delivery and payment for a product are determined at the same time.
[MD3:] Net load balancing services offered into wholesale power markets generally take the form of power-paths that can be dispatched at specific grid locations over time.\(^3\)

[MD4:] All dispatchable resources should be permitted to compete for the provision of power-paths in wholesale power markets without regard for irrelevant underlying technological differences.

A swing-contract market design is proposed that is in accordance with principles MD1-MD4. This design envisions an ISO-managed wholesale power market \(M(T)\) organized as a reserve market for some designated future operating period \(T\). Reserve consists of dispatchable power-paths for period \(T\). As illustrated in Fig. 1.1, a power-path for period \(T\) refers to power injected and/or withdrawn at a single designated grid location during period \(T\). Dispatchable resources offer reserve (dispatchable power-paths) into \(M(T)\) by means of “swing contracts.”

![Fig. 1.1 One of many possible power-paths that a dispatchable resource with swing (flexibility) in down/up ramping and power amplitude could be signaled to deliver at its grid location during operating period \(T = [t_s, t_e]\).](image)

More precisely, as carefully explained in Chapter 4, a swing contract \(SC_m\) issued by a dispatchable resource \(m\) is a reserve contract that \(m\) can offer into a swing-contract market \(M(T)\) in either firm or option form.\(^5\) \(SC_m\) consists of four

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\(^3\) As discussed in [46, 60], primary frequency response is synchronized reserve capacity that autonomously responds to changes in system frequency; consequently, it is not dispatched. The provision and compensation of primary frequency response is not considered in the current study.

\(^4\) Since a power-path refers to the injection and/or withdrawal of power at a single grid location over time, a power-path is characterized without reference to spatial transmission. As illustrated in Fig. 1.1, power-paths can be depicted in a time-power plane.

\(^5\) As explained more fully in Chapter 4, a firm contract is a non-contingent contract that imposes obligations on both the issuer and the holder. An option contract is a contingent contract that gives the holder the right, but not the obligation, to exercise the contract at one or more contractually specified exercise times. The exercise of an option contract converts it into a firm contract.
components, each specified by $m$: (i) an offer price $\alpha_m$; (ii) an exercise set $\mathbb{T}_{ex}^m$; (iii) a physically characterized set $\mathbb{PP}_m$ of power paths for period $T$, each of which $m$ could feasibly deliver at a designated grid location during $T$ in response to dispatch signals; and (iv) a performance payment method $\phi_m$.

If $SC_m$ is cleared, the offer price $\alpha_m$ (if positive) is paid to $m$ either directly or in amortized payment-schedule form. The offer price thus permits $m$ to cover ex ante any cost that $m$ would have to incur to ensure the availability of the power-paths in $\mathbb{PP}_m$. This availability cost could include capital investment cost, start-up cost, no-load cost, and opportunity cost. The exercise set $\mathbb{T}_{ex}^m$ consists of designated times between the close of $M(T)$ and the start of $T$ at which the ISO can exercise $SC_m$, assuming $SC_m$ has been cleared. The form of this exercise set determines whether $SC_m$ is a firm contract or a type of option contract.6

The dispatchable power-paths in $\mathbb{PP}_m$ are characterized in terms of attributes such as delivery location, start-time, minimum down/up time, active and reactive power limits, ramp-rate limits, duration limits, and energy capacity. The precise specification of these attributes determines the degree of swing (flexibility) in $m$’s offered reserve. Finally, the performance payment method $\phi_m$ permits resource $m$ to recover ex post any cost that $m$ incurs for verified period-$T$ service performance, i.e., for the verified period-$T$ delivery of a power-path in $\mathbb{PP}_m$ in response to dispatch signals. This performance cost could include fuel cost, labor cost, transmission service charges, and machinery wear and tear caused by fast ramping.

**Reserve offers** submitted into $M(T)$ take the form of portfolios of swing contracts offered by dispatchable resources for operating period $T$. These dispatchable resources can include generators, distributed-resource aggregators, and storage facilities. Reserve offers in firm form effectively constitute regulation reserve whereas reserve offers in option form effectively constitute contingency or planning reserve.

As demonstrated in Chapter 5, these reserve offers can take the standard supply-offer forms required by current U.S. RTO/ISO-managed wholesale power markets. Examples include: must-run energy blocks; hourly step-function power supply schedules with a separate price designated for each power-step; and power self-scheduled by power traders to secure needed transmission support for the power outcomes of privately negotiated physically covered bilateral contracts.

However, as is also demonstrated in Chapter 5, the general formulation of a swing contract can accommodate reserve offers with a much broader range of offered attributes than envisioned in these standard supply offer forms. Moreover, the issuer $m$ of a swing contract $SC_m$ can use the performance payment method $\phi_m$ included in $SC_m$ to specify $m$’s required compensation ex post for dynamic aspects of a delivered power-path, such as ramping, duration, and reactive power support, as well as static aspects such as total delivered energy.

**Reserve bids** submitted into a swing-contract market $M(T)$ take the form of price-sensitive and/or fixed demands for power-path delivery during operating period $T$. Reserve bids can be submitted by load-serving entities to service the forecasted loads of their customers during $T$, and by power traders who need to self-schedule

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6 As will be clarified in Section 4.3, standard types of option contracts are distinguished by the number and positioning of their exercise times.
the power outcomes of privately negotiated physically covered bilateral contracts in order to secure needed transmission support.

As detailed in Chapters 6–9, an ISO managing a swing-contract market M(T) solves a contract-clearing optimization problem to determine which reserve offers and price-sensitive reserve bids to clear for operating period T. The objective of the ISO is to maximize the expected total net benefit of the market participants, conditional on initial state conditions and subject to system constraints.

Total net benefit consists of total benefit net of total avoidable cost. The system constraints include power balance, transmission line, and reserve constraints. These constraints incorporate, as exogenous inputs: (i) all fixed demands; (ii) all forecasts for non-dispatched power injection; (iii) all of the power-path attributes included by dispatchable resources in their reserve offers; and (iv) system-wide and zonal reserve requirements set by the ISO to ensure coverage of net load uncertainty sets as a robust means of protection against net load forecast errors.

The ISO functions as a clearing house for M(T), collecting payments and overseeing payouts to market participants. However, the ISO does not have any financial stake in market operations. To maintain this independent status, all net reserve cost and transmission service cost incurred through market operations are passed through to market participants. Net reserve cost is allocated across market participants based on the relative volatility and size of their net must-service load. Transmission service cost is allocated across market participants based on the power imbalance at their grid locations.

More generally, Chapter 10 proposes a linked collection of swing-contract markets whose look-ahead horizons for designated future operating periods can range in duration from multiple years to minutes. The linkage among these markets is achieved by having the reserve offers and price-sensitive reserve bids cleared in earlier markets be carried forward on the books of the ISO as a portfolio of contracts that can be adaptively updated in subsequent markets. This linkage facilitates reserve procurement by permitting a successively refined understanding of resource availability and system conditions for future operating periods.

The key features of this Linked Swing-Contract Market Design in comparison with current U.S. RTO/ISO-managed wholesale power market designs, elaborated in Chapters 10–15, are summarized below:

- permits the robust-control management of uncertain net load
- handles uncertain net load by ensuring flexible dependable reserve supply
- eliminates the need for detailed net load scenario specifications
- facilitates a level playing field for resource participation

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7 Net reserve cost is reserve procurement cost net of any price payments for cleared price-sensitive reserve bids and net of any penalty payments for real-time deviations from dispatch signals.

8 The net must-service load of a market participant at a particular grid location is the amount of its non-dispatched power withdrawal at that location, if any, minus the amount of its non-dispatched power injection at that location, if any.

9 Power imbalance is said to occur at a particular bus in a transmission grid if there is a non-zero net power injection at this bus that requires the transmission of power to or from other buses in order to ensure power balance across the transmission grid as a whole.
recognizes the forward nature of wholesale power markets
- recognizes all offered product in these forward markets is a form of reserve
- identifies reserve as dispatchable power-paths available for future operations
- requires resources to internally manage commitment and capacity constraints
- permits co-optimization across a wide range of reserve attributes
- ensures settlement time-consistency through two-part pricing
- compensates reserve availability ex ante and reserve deployment ex post
- permits resource owners to cover ex ante their full costs of availability
- permits resource owners to recover ex post their full real-time performance costs
- eliminates the need for out-of-market payment adjustments
- provides system operators with real-time flexibility for net load balancing
- encourages close following of dispatch signals through performance incentives
- reduces the complexity of market rules

Chapter 16 considers how current U.S. RTO/ISO-managed day-ahead markets could gradually transition to a swing-contract market design. As shown, a swing contract submitted by a dispatchable resource into a day-ahead market can in principle be incorporated as follows. First, the swing-contract’s offer price and performance payment method can be incorporated into the objective function for the optimization used by the RTO/ISO to solve for generator unit commitments and scheduled dispatch levels for next-day operations. Second, the power-path attributes designated by this swing contract can be incorporated into the system constraints for this optimization.

However, in order for this incorporation to result in accurate merit-order dispatch for next-day operations, the optimization would have to account fully for the expected total net benefit associated with each possible configuration of generator unit commitments and scheduled dispatch levels. At present this is not the case. For example, the unit commitment costs appearing in the objective function typically cover (at most) the start-up, no-load, and minimum-run costs of generators, not their full availability costs. Also, voltage limits are typically not included among the system constraints, thus preventing consideration of the benefits provided by offered voltage-support services. In consequence, swing contracts offering diverse dispatchable power-paths, with explicit offer prices and performance payment methods ensuring full coverage of availability and performance costs, could be incorrectly omitted from the merit-order dispatch stack on the grounds they are too costly.

To illustrate what might be done to address this issue, Chapter 16 presents an extended day-ahead market optimization in complete analytical form that permits a fuller range of costs to be incorporated in the objective function. It is shown, explicitly, how swing contracts offering dispatchable power-paths with swing (flexibility) in power amplitude and ramp rate can be incorporated into this extended optimization along with standard types of supply offers while still retaining a mixed-integer linear programming formulation. The solution of this extended optimization results in an accurate merit-order dispatch stack.

Chapters 17–18 explore swing-contract support for integrated transmission and distribution system operations; see Fig. 1.2. Special attention is focused on the possibility that Independent Distribution System Operators (IDSOs), functioning in dis-
Distribution systems as grid-edge resource aggregators,\textsuperscript{10} could use swing contracts to facilitate their participation in transmission systems as reserve providers as well as load-serving entities. The reserve provision of an IDSO could take the form of swing contracts offering the availability of dispatchable power-paths harnessed from grid-edge resources in return for appropriate compensation. This IDSO participation would permit retail customer interests to be more directly and completely represented at the wholesale power market table.

Potential future research directions are outlined in Chapter 19, and concluding remarks are given in Chapter 20. Glossaries and nomenclature tables for terms used to describe market operations in both standard and swing-contract forms are provided in Chapter 21.

\textsuperscript{10} In this study a grid-edge resource is defined to be any entity capable of power usage and/or power output that is directly connected to a distribution grid. A grid-edge resource aggregator is any entity that manages power usage, power supply, and/or ancillary service provision for a collection of grid-edge resources.
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