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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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Contents

1 Introduction . . . 9

2 U.S. RTO/ISO-Managed Wholesale Power Markets: Overview . . . 15
  2.1 Chapter Preview . . . 15
  2.2 General Goals for Wholesale Power Market Design . . . 15
  2.3 U.S. RTO/ISO-Managed Market Operations . . . 16
  2.4 Stresses Faced by Current U.S. RTO/ISO-Managed Markets . . . 19

3 Motivation for Current Study . . . 21
  3.1 Chapter Preview . . . 21
  3.2 Problematic Design Aspects of U.S. RTO/ISO-Managed Wholesale Power Markets . . . 21
    3.2.1 Artificial Distinction Between Energy and Reserve . . . 21
    3.2.2 Problematic Use of Hedonic Pricing . . . 22
    3.2.3 Revenue Insufficiency and Incentive Problems . . . 23
    3.2.4 Computational Fragility of LMP Derivations . . . 24
    3.2.5 Performance Payment in Advance of Performance Delivery . 26
    3.2.6 Minimal Direct Representation of Retail Customer Interests 27
    3.2.7 Reliance on Overly Simplistic Cost Conceptions . . . 28
    3.2.8 Use of Spot-Market Pricing for Forward Markets . . . 30
  3.3 Relation of Current Study to Previous Swing-Contract Work . . . 30

4 Swing Contracts for ISO-Managed Wholesale Power Markets . . . 33
  4.1 Swing Contract Overview . . . 33
  4.2 Swing Contracts: General Formulation . . . 33
  4.3 Swing Contracts in Firm or Option Form . . . 35

5 Illustrative Swing-Contract Reserve Offers . . . 37
  5.1 Chapter Preview . . . 37
  5.2 A Simple Energy-Block Swing Contract in Firm Form . . . 38
  5.3 An Energy-Block Swing Contract in Option Form . . . 42

5.4 Swing-Contract Implementation of Standard Supply Offers 43
5.5 A Swing Contract Offering Continuous Swing (Flexibility) in Power and Ramp 48
5.6 A Swing Contract Offering Battery Services 50
5.7 Swing-Contract Facilitation of Private Bilateral Contracting 52

6 Swing-Contract Market Design 55
6.1 Chapter Preview 55
6.2 General Swing-Contract Market Formulation 55
6.3 Financial and Physical Feasibility of Swing-Contract Offers 57
6.4 Reserve Bids 58
6.5 Handling of Fixed Reserve Bids and Non-Dispatched Power 59
6.6 Performance Penalties and Incentives 60
6.7 ISO Cost Allocation 61

7 Swing-Contract Market Optimization: Base-Case MILP Formulation 65
7.1 Chapter Preview 65
7.2 General Assumptions and Notation 66
7.3 Discretization of the ISO's Optimization Problem 67
7.4 ISO Objective Function 71
7.5 Complete Analytical MILP Formulation 72
7.6 Additional Discussion of Optimization Aspects 74
7.7 Five-Bus Test Case 76
7.8 Thirty Bus Test Case with Adaptive Reserve Zones 79

8 Inclusion of Reserve Offers with Price Swing 83
8.1 Chapter Preview 83
8.2 Cost Function Preliminaries 83
8.3 MILP Tractable Form of Reserve Offers with Price Swing 85

9 Inclusion of Price-Sensitive Reserve Bids 91
9.1 Chapter Preview 91
9.2 Incorporation of Benefits 92
9.3 Modeling of Price-Sensitive Reserve Bids 94
  9.3.1 Standard Demand Function Formulation 94
  9.3.2 Reserve Bids with Time-of-Use Pricing 95
  9.3.3 Reserve Bids with Price Swing 95
  9.3.4 Reserve Bids Directly Expressed as Benefit Functions 97
9.4 MILP Tractable Approximation of Benefit Functions 98

10 The Linked Swing-Contract Market Design 101
10.1 Chapter Preview 101
10.2 Multistage Optimization and Time Inconsistency 102
10.3 Settlement Time-Consistency of Swing-Contract Markets 105
10.4 Swing-Contract Long-Term Forward Markets 106
10.5 Swing-Contract Short-Term Forward Markets 107

10.6 Swing-Contract Very Short-Term Forward Markets 109
10.7 Swing-Contract Deployment in Real-Time Operations 110

11 Illustration: Linked Day-Ahead and Hour-Ahead Swing-Contract Markets 113
11.1 Chapter Preview 113
11.2 Hour-Ahead Market with Reserve Offers Consisting of Swing-Contract Portfolios 114
11.3 SCED Solution for Hour-Ahead Swing-Contract Market 117
11.3.1 Overview 117
11.3.2 Power Balance 117
11.3.3 Coverage of the ISO's Uncertainty Set 119
11.3.4 Constrained Minimization of Expected Cost 121
11.4 Linked Day-Ahead and Hour-Ahead Markets 121

12 Standard Modeling of a Competitive Market 125
12.1 Chapter Preview 125
12.2 Key Definitions 125
12.3 Standard Competitive Market Assumptions 126
12.4 Law of One Price for Commodities 126
12.5 Competitive Market: Basic Formulation 127
12.6 Net Surplus Extraction 130
12.7 Market Efficiency Metric 131
12.8 Market Efficiency and Pricing Rules 133
12.9 Strategic Trade Behavior and Trader Market Power 134

13 U.S. RTO/ISO-Managed Markets: Efficiency and Market Power 137
13.1 Chapter Preview 137
13.2 Daily Market Operations 137
13.3 Illustrative Analytical DAM Formulation 140
13.4 Net Surplus Extraction in the Illustrative DAM 141
13.5 Market Power in the Illustrative DAM: Type-I Error 145
13.6 Market Power in the Illustrative DAM: Type-II Error 149
13.7 Market Inefficiency in the Illustrative DAM 153
13.8 DAM Performance: General Assessment 156
13.9 Scheduling of Bilateral Contracts 158

14 Comparisons with Swing-Contract Markets 161
14.1 Chapter Preview 161
14.2 Product Definition in U.S. RTO/ISO-Managed Markets 162
14.3 Wholesale Power and the Law of One Price (Not) 164
14.4 Differential vs. Uniform Pricing 165
14.5 Comparison of SC and Current U.S. DAM Designs 166

15 Advantages of the Linked Swing-Contract Market Design 169
15.1 Chapter Preview 169
15.2 SC Markets are Physically-Covered Insurance Markets 170
15.3 Longer-Term SC Markets Support New Investment 171
15.4 SC Markets Ensure Revenue Sufficiency 176
15.5 SC Markets Ameliorate Merit-Order Concerns 177
15.6 SC Markets are Robust-Control Mechanisms 178
15.7 SC Markets Reduce Rule Complexity 179
15.8 SC Markets Reduce Gaming Opportunities 180
15.9 SC Markets Have Smaller-Sized Optimizations 182
15.10 Additional Advantages of SC Markets 183
  15.10.1 Ensure a Level Playing Field for Resource Participation . . . 183
  15.10.2 Permit Co-Optimization of Diverse Reserve 184
  15.10.3 Appropriately Remunerate Diversity and Flexibility 184
  15.10.4 Encourage Accurate Forecasting and Dispatch Following . . 184
  15.10.5 Ensure Settlement Time-Consistency 184

16 Gradual Transition to Linked Swing-Contract Markets 185
16.1 Chapter Preview 185
16.2 A DAM Formulation Permitting Gradual Transition 187
16.3 Cost Function Preliminaries for the Transitional DAM 189
16.4 MILP SCUC/SCED Optimization for the Transitional DAM 192

17 Swing-Contract Support for Integrated Transmission and Distribution Systems 201
17.1 Chapter Preview 201
17.2 Transactive Energy System Design for ITD Systems 203
17.3 Role of Distribution Utilities 207
17.4 An IDSO-Managed Bid-Based TES Design for Households 208
17.5 IDSOs as Grid-Edge Resource Aggregators 211
17.6 Swing-Contract Support for IDSO Participation in Wholesale Power Markets 212

18 Design Evaluation via the ITD TES Platform 213
18.1 Chapter Preview 213
18.2 Design Readiness Levels 213
18.3 An ITD TES Platform Permitting TES Design Evaluation 216
18.4 Illustrative Test Cases: Overview 218
18.5 Illustrative Test Cases: Report 221

19 Potential Future Research Directions 227

20 Conclusion: The Dots Keep Connecting 231

21 Appendices 233
21.1 Quick-Reference Glossary of Standard Acronyms 233
21.2 Quick-Reference Glossary of Transmission System Terms 234
21.3 Quick-Reference Glossary of Economic Terms 235
21.4 Nomenclature for a Swing-Contract Market 236
21.5 Nomenclature for a Distribution System 238

References 239

Chapter 1
Introduction

> "Design to the mission, design as a system, keep it simple." [109, 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 [58] 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 a sequence of power injections and/or withdrawals at a single designated grid location during period T.[4] Dispatchable resources offer reserve (dispatchable power-paths) into M(T) by means of "swing contracts."

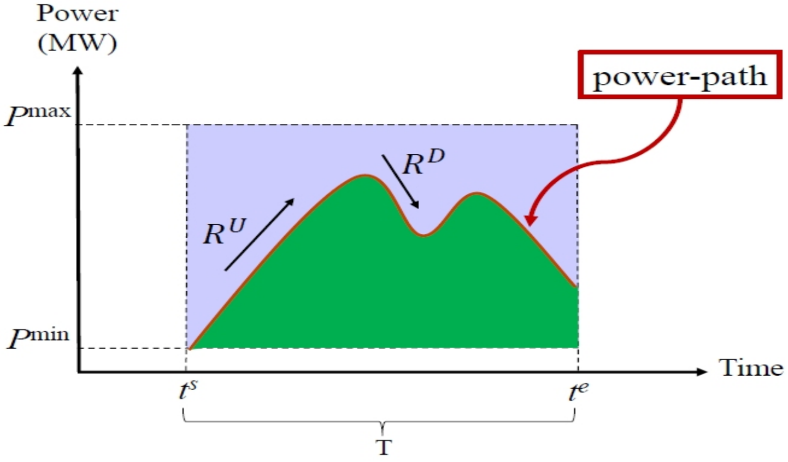

Fig. 1.1 One of many possible power-paths that a dispatchable resource with swing (flexibility) in down/up ramping and power amplitude could be signaled to deliver at its grid location during operating period T = $[t^s, t^e)$.

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, 59], *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 α_m; (ii) an exercise set $\mathbb{T}_m^{\mathrm{ex}}$; (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 ϕ_m.

If SC_m is cleared, the offer price α_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 $\mathbb{T}_m^{\mathrm{ex}}$ 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 ϕ_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 ϕ_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[7] 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.[8] Transmission service cost is allocated across market participants based on the power imbalance[9] 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-

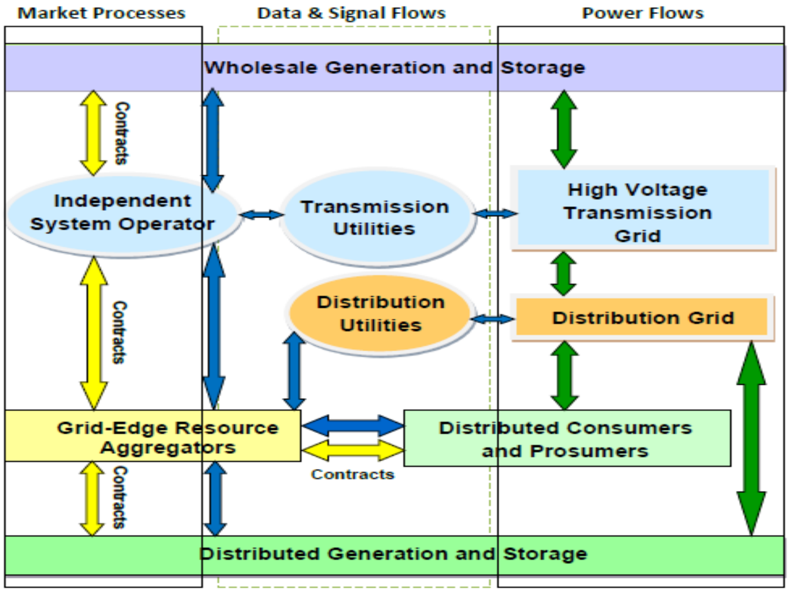

Fig. 1.2 Illustration of an integrated transmission and distribution system.

tribution systems as grid-edge resource aggregators,[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.

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[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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