## TABLE OF CONTENTS

PREFACE	
SECTION 1 INTRODUCTION	1
2019 in Review	1
PJM Market Summary Statistics	1 4
PJM Market Background	4
Conclusions	6
Energy Market Conclusion	6
Capacity Market Conclusion	8
Tier 2 Synchronized Reserve Market Conclusion	9
Day-Ahead Scheduling Reserve Market Conclusion	9
Regulation Market Conclusion	10
FTR Auction Market Conclusion	10
Role of MMU	11
Reporting	11
Monitoring	11
Market Design	12
New Recommendations	12
New Recommendations from Section 3, Energy Market	13
New Recommendations from Section 5, Capacity Market	13
New Recommendation from Section 6, Demand Response	13
New Recommendation from Section 7, Net Revenue	13
New Recommendations from Section 8, Environmental and Renewable Energy Regulations	13
New Recommendation from Section 9, Interchange Transactions	14
New Recommendations from Section 10, Ancillary Services	14
New Recommendations from Section 12, Generation and Transmission Planning	14
Total Price of Wholesale Power	14
Components of Total Price	15
Section Overviews	21
Overview: Section 3, Energy Market	21
Overview: Section 4, Energy Uplift	31
Overview: Section 5, Capacity Market	35
Overview: Section 6, Demand Response	44
Overview: Section 7, Net Revenue	49
Overview: Section 8, Environmental and Renewables	50
Overview: Section 9, Interchange Transactions	54
Overview: Section 10, Ancillary Services	57
Overview: Section 11, Congestion and Marginal Losses	66
Overview: Section 12, Planning	68
Overview: Section 13, FTRs and ARRs	74

SECTION 2 RECOMMENDATIONS	81
New Recommendations	81
New Recommendations from Section 3, Energy Market	82
New Recommendation from Section 5, Capacity Market	82
New Recommendation from Section 6, Demand Response	82
New Recommendation from Section 7, Net Revenue	82
New Recommendations from Section 8, Environmental and Renewable Energy Regulations	82
New Recommendation from Section 9, Interchange Transactions	83
New Recommendation from Section 10, Ancillary Services	83
New Recommendations from Section 12, Generation and Transmission Planning	83
History of MMU Recommendations	83
Complete List of Current MMU Recommendations	85
Section 3, Energy Market	85
Section 4, Energy Uplift	88
Section 5, Capacity Market	90
Section 6, Demand Response	93
Section 7, Net Revenue	95
Section 8, Environmental	95
Section 9, Interchange Transactions	95
Section 10, Ancillary Services	96
Section 11, Congestion and Marginal Losses	98
Section 12, Planning	98
Section 13, FTRs and ARRs	100
Adopted Recommendations	102
Adopted 2019	102
Adopted 2018	102
Adopted 2017	102
Adopted 2016	102
Adopted 2015	103
Adopted 2014	104
Adopted 2013	104
Adopted 2012	105
Adopted 2011	105
Adopted 2010	106
Adopted 2009	106
Adopted 2008	107
Adopted 2006	107

SECTION 3 ENERGY MARKET	109
Overview	110
Supply and Demand	110
Competitive Assessment	112
Recommendations	114
Conclusion	117
Supply and Demand	120
Market Structure	120
Market Behavior	131
Supply and Demand: Load and Spot Market	131
Generator Offers	132
Parameter Limited Schedules	134
Virtual Offers and Bids	139
Market Performance	150
LMP	150
Zonal LMP and Dispatch	162
Fuel Prices, LMP, and Dispatch	164
Components of LMP	170
Scarcity	174
Emergency Procedures	175
Analysis of October 1 Events	176
Analysis of October 2 Performance Assessment Intervals	180
Scarcity and Scarcity Pricing	186
PJM Cold Weather Operations 2019	192
Competitive Assessment	193
Market Structure	193
Market Behavior	197
Market Performance	214
Market Structure, Participant Behavior, and Market Performance	223
SECTION 4 ENERGY UPLIFT (OPERATING RESERVES)	225
Overview	225
Energy Uplift Credits	225
Energy Uplift Charges	226
Geography of Charges and Credits	226
Recommendations	226
Conclusion	228
Energy Uplift Credits Results	229
Characteristics of Credits	230
Types of Units	230
Day-Ahead Unit Commitment for Reliability	231
Balancing Operating Reserve Credits	232

Lost Opportunity Cost Credits	234
Uplift Eligibility	235
Economic and Noneconomic Generation	236
Concentration of Energy Uplift Credits	237
Credits and Charges Categories	239
Energy Uplift Charges Results	241
Energy Uplift Charges	241
Operating Reserve Rates	244
Reactive Services Rates	246
Balancing Operating Reserve Determinants	247
Geography of Charges and Credits	247
Energy Uplift Issues	249
Events on October 1-2, 2019	249
Intraday Segments Uplift Settlement	249
SECTION 5 CAPACITY MARKET	251
Overview	252
RPM Capacity Market	252
Reliability Must Run Service	254
Generator Performance	254
Recommendations	254
Conclusion	257
Installed Capacity	262
Fuel Diversity	264
RPM Capacity Market	264
Market Structure	265
Market Conduct	274
Market Performance	283
Reliability Must Run (RMR) Service	290
Generator Performance	292
Capacity Factor	292
Generator Performance Factors	293
Generator Forced Outage Rates	294

SECTION 6 DEMAND RESPONSE	297
Overview	297
Recommendations	298
Conclusion	299
PJM Demand Response Programs Non-PJM Demand Response Programs Participation in Demand Response Programs Economic Program	302
	303
	304
	305
Emergency and Pre-Emergency Programs	312
Distributed Energy Resources	325
SECTION 7 NET REVENUE	327
Overview	327
Net Revenue	327
Recommendations	328
Historical New Entrant CC Revenue Adequacy	328
Conclusion	328
Net Revenue	328
Spark Spreads, Dark Spreads, and Quark Spreads	329
Theoretical Energy Market Net Revenue	331
Capacity Market Net Revenue	333
Net Revenue Adequacy	333
Levelized Total Costs	334
Levelized Cost of Energy	334
New Entrant Combustion Turbine	334
New Entrant Combined Cycle	336
New Entrant Coal Plant	337
New Entrant Nuclear Plant	338
New Entrant Diesel	339
New Entrant Onshore Wind Installation	340
New Entrant Offshore Wind Installation	340
New Entrant Solar Installation	341
Historical New Entrant CC Revenue Adequacy	342
Factors in Net Revenue Adequacy	343
Actual Net Revenue	344
Nuclear Net Revenue Analysis	347

SECTION 8 ENVIRONMENTAL AND RENEWABLE ENERGY REGULATIONS	355
Overview	355
Federal Environmental Regulation	355
State Environmental Regulation	356
State Renewable Portfolio Standards	356
Emissions Controls in PJM Markets	356
Renewable Generation	356
Recommendations	357
Conclusion	357
Federal Environmental Regulation	359
CAA: NESHAP/MATS	359
CAA: NAAQS/CSAPR	360
CAA: NSR	360
CAA: RICE	361
CAA: Greenhouse Gas Emissions	361
CWA: WOTUS Definition and Effluents	362
RCRA: Coal Ash	362
State Environmental Regulation	363
State Emissions Regulations	363
State Regulation of Greenhouse Gas Emissions	363
State Renewable Portfolio Standards	368
Carbon Pricing	380
Alternative Compliance Payments	381
Emission Controlled Capacity and Emissions	384
Emission Controlled Capacity	384
Emissions	385
Renewable Energy Output	387
Wind and Solar Peak Hour Output	387
Wind Units	388
Solar Units	390
SECTION 9 INTERCHANGE TRANSACTIONS	393
Overview	393
Interchange Transaction Activity	393
Interactions with Bordering Areas	393
Recommendations	394
Conclusion	395
Interchange Transaction Activity	395
Charges and Credits Applied to Interchange Transactions	395
Aggregate Imports and Exports	396
Real-Time Interface Imports and Exports	398

viii Table of Contents © 2020 Monitoring Analytics, LLC

	Real-Time Interface Pricing Point Imports and Exports	400
	Day-Ahead Interface Imports and Exports	403
	Day-Ahead Interface Pricing Point Imports and Exports	406
	Loop Flows	412
	PJM and MISO Interface Prices	418
	PJM and NYISO Interface Prices	420
	Summary of Interface Prices between PJM and Organized Markets	422
	Neptune Underwater Transmission Line to Long Island, New York	422
	Linden Variable Frequency Transformer (VFT) facility	423
	Hudson Direct Current (DC) Merchant Transmission Line	425
	Interchange Activity During High Load Hours	426
0	perating Agreements with Bordering Areas	426
	PJM and MISO Joint Operating Agreement	427
	PJM and New York Independent System Operator Joint Operating Agreement (JOA)	428
	PJM and TVA Joint Reliability Coordination Agreement (JRCA)	430
	PJM and Duke Energy Progress, Inc. Joint Operating Agreement	430
	PJM and VACAR South Reliability Coordination Agreement	430
	Balancing Authority Operations Coordination Agreement between Wisconsin Electric Power	
	Company (WEC) and PJM Interconnection, LLC	430
	Northeastern ISO-Regional Transmission Organization Planning Coordination Protocol	430
	Interface Pricing Agreements with Individual Balancing Authorities	431
ln	terchange Transaction Issues	432
	PJM Transmission Loading Relief Procedures (TLRs)	432
	Up To Congestion	433
	Sham Scheduling	435
	Elimination of Ontario Interface Pricing Point	435
	PJM and NYISO Coordinated Interchange Transactions	437
	Reserving Ramp on the PJM/NYISO Interface	440
	PJM and MISO Coordinated Interchange Transaction Proposal	440
	Willing to Pay Congestion and Not Willing to Pay Congestion	444
	Spot Imports	445
	Interchange Optimization	445
	Interchange Cap During Emergency Conditions	446
	45 Minute Schedule Duration Rule	446
	MISO Multi-Value Project Usage Rate (MUR)	447

ECTION 10 ANCILLARY SERVICE MARKETS	449
Overview	450
Primary Reserve	450
Tier 1 Synchronized Reserve	450
Tier 2 Synchronized Reserve Market	451
Nonsynchronized Reserve Market	451
Secondary Reserve	452
Regulation Market	453
Black Start Service	454
Reactive	454
Frequency Response	455
Ancillary Services Costs per MWh of Load: 1999 through 2019	455
Recommendations	456
Conclusion	458
Primary Reserve	459
Market Structure	459
Price and Cost	463
Tier 1 Synchronized Reserve	464
Market Structure	464
Tier 1 Synchronized Reserve Payments	466
Tier 2 Synchronized Reserve Market	469
Market Structure	469
Market Behavior	471
Market Performance	473
Nonsynchronized Reserve Market	478
Market Structure	479
Secondary Reserve	481
Market Structure	481
Market Conduct	482
Market Performance	483
Regulation Market	485
Market Design	485
Market Structure	496
Market Conduct	500
Market Performance	504
Black Start Service	507
NERC – CIP	509
Minimum Tank Suction Level (MTSL)	509
Reactive Service	510
Recommended Market Approach to Reactive Costs	511
Improvements to Current Approach	511
Reactive Costs	514
Frequency Response	515
Frequency Control Definition	515

SECTION 11 CONGESTION AND MARGINAL LOSSES	517
Overview	518
Congestion Cost	518
Marginal Loss Cost	518
System Energy Cost	519
Conclusion	519
Issues	519
Closed Loop Interfaces and CT Pricing Logic	519
Balancing Congestion Cost Calculation Logic Change	521
Locational Marginal Price (LMP)	522
Components	522
Hub Components	526
Congestion	526
Congestion Accounting	526
Total Congestion	529
Congested Facilities	538
Congestion by Facility Type and Voltage	539
Constraint Frequency	542
Constraint Costs	543
Congestion Event Summary: Impact of Changes in UTC Volumes	546
Marginal Losses	546
Marginal Loss Accounting	546
Total Marginal Loss Cost	548
System Energy Costs	552
Energy Accounting	552
Total System Energy Costs	552
SECTION 12 GENERATION AND TRANSMISSION PLANNING	555
Overview	555
Generation Interconnection Planning	555
Regional Transmission Expansion Plan (RTEP)	556
Transmission Facility Outages	557
Recommendations	557
Conclusion	560
Generation Interconnection Planning	561
Existing Generation Mix	561
Generation Retirements	563
Generation Queue	567
Regional Transmission Expansion Plan (RTEP)	586
RTEP Process	586
Market Efficiency Process	586
PJM MISO Interregional Market Efficiency Process (IMEP)	588
= * * * * * * * * * * * * * * * * * * *	

PJM MISO Targeted Market Efficiency Process (TMEP)	589
Supplemental Transmission Projects	589
Board Authorized Transmission Upgrades	594
Qualifying Transmission Upgrades (QTU)	594
Cost Allocation	594
Transmission Line Ratings	595
Transmission Facility Outages	597
Scheduling Transmission Facility Outage Requests	597
Rescheduling Transmission Facility Outage Requests	600
Long Duration Transmission Facility Outage Requests	601
Transmission Facility Outage Analysis for the FTR Market	602
Transmission Facility Outage Analysis in the Day-Ahead Energy Market	608
SECTION 13 FINANCIAL TRANSMISSION AND AUCTION REVENUE RIGHTS	611
Overview	613
Auction Revenue Rights	613
Financial Transmission Rights	614
Recommendations	615
Conclusion	616
Auction Revenue Rights	619
ARRs	619
IARRs	619
Market Structure	620
Market Performance	622
Financial Transmission Rights	623
Market Structure	624
Market Performance	628
Revenue Adequacy	635
FTR Revenue Adequacy and Stage 1B/Stage 2 ARR Allocations	636
Surplus Congestion Revenue	636
ARR and FTR Revenue Adequacy	637
FTR Uplift Charge	640
Revenue Adequacy Issues and Solutions	640
ARRs as an Offset to Congestion for Load	641
FERC Order on FTRs: Balancing Congestion and M2M Payment Allocation	641
Zonal ARR Congestion Offset	642
Day-Ahead Congestion and FTR Auction Price Convergence	645
Credit	646
GreenHat Settlement Proceedings	646
FTR Forfeitures	646
Hourly FTR Cost	646
FFRC Order on FTR Forfeitures	647