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TECHNOLOGY

Reliability Attributes – Metrics, Scoring Methodology, and Rankings

Final Report

Nov 2, 2021

Executive Summary (1/2)

- Operating a power system with very high levels of inverter-based resources (IBR) requires careful analysis of the system reliability attributes to ensure a safe and reliable operation during normal, emergency, and islanded system conditions.

- This study evaluated nine portfolios across 8 reliability metrics involving 14 measures. The study focused on the year 2030 for all quantitative analyses. The goal is to assess the ability of NIPSCO to reliably serve its baseload within its service territory:
  - Under normal operating conditions, NIPSCO is strongly tied to MISO and PJM's systems and relies on MISO for dispatch of its resources, the balancing of its energy requirements, and the control of frequency. Areas of reliability assessment focused on:
    - deliverability of dynamic reactive power to load centers, short circuit strength, predictability of portfolio output, and the increased need for regulation reserves.
  - Under emergency market conditions, such as max gen events, the areas of reliability assessment focused on:
    - exposure to energy imports.
  - Under islanded conditions, the reliability assessments focused on:
    - blackstart and restoration, short circuit strength, ability to control frequency (inertial and primary frequency response), ramping capability, and energy adequacy to serve the critical demand of customers.

- The portfolios were ranked from a reliability perspective. The top 5 portfolios with the least levels of reliability concerns across the various metrics are in order: F, I, C, E, and H.

Executive Summary (2/2)

- Reliability concerns were identified for each portfolio, especially under emergency and islanded conditions, and mitigation measures were identified as follows:
    - Stand-alone energy storage should have grid-forming inverters (GFM) with additional capabilities including blackstart and fast frequency response (FFR). GFM inverters are not widely used today in the US market, but the technology is available and is recommended for portfolios with high penetration of IBRs.
    - Gas peakers and combined cycle units in portfolios C, F, and I should have blackstart capability.
    - The provision of additional energy storage resources in some portfolios.
    - Specifications of short circuit ratio (SCR) of inverters not to exceed 3.
    - Provision of additional synchronous condensers to increase the grid's short circuit strength ranging from 0 to 802 MVAr.
- Areas not covered by this study:
    - The study assumed that any required grid upgrades will be implemented as part of MISO interconnection process, and thus excluded the analysis of portfolio deliverability.
    - The study assumed the IRP process produced portfolios with sufficient capacity to assure meeting the LOLE target of 0.1 days/year, and thus excluded the analysis of resource adequacy.
    - All reliability assessments in this study applied screening level indicative analyses. Detailed system studies are essential and should be conducted to properly assess system reliability of the short-listed Portfolios.

Reliability Assessment and Ranking

Assess NIPSCO's Reliability Needs

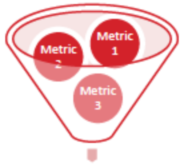
- Power Ramping
- Frequency Response
- Short Circuit Strength
- Blackstart
- Energy Adequacy
- Frequency Regulation
- Dynamic VARs
- Grid Topology

Review & Update Reliability Metrics

Apply a Series of Reliability Filters to IRP Portfolios

Scoring Criteria

Ranking Portfolios



Preferred Portfolio

Reliability Criteria

	Criteria	Description	Rationale
1	Blackstart	Resource has the ability to be started without support from the wider system or is designed to remain energized without connection to the remainder of the system, with the ability to energize a bus, supply real and reactive power, frequency and voltage control	In the event of a black out condition, NIPSCO must have a blackstart plan to restore its local electric system. The plan can either rely on MISO to energize a cranking path or on internal resources within the NIPSCO service territory.
2	Energy Adequacy	Resources are able to meet the energy and capacity duration requirements. Portfolio resources are able to supply the energy demand of customers during MISO's emergency max gen events, and also to supply the energy needs of critical loads during islanded operation events.	NIPSCO must have long duration resources to serve the needs of its customers during emergency and islanded operation events.
3	Dispatchability and Automatic Generation Control	The unit will respond to directives from system operators regarding its status, output, and timing. The unit has the ability to be placed on Automatic Generation Control (AGC) allowing its output to be ramped up or down automatically to respond immediately to changes on the system.	MISO provides dispatch signals under normal conditions, but NIPSCO requires AGC attributes under emergency restoration procedures or other operational considerations
4	Operational Flexibility and Frequency Support	Ability to provide inertial energy reservoir or a sink to stabilize the system. The resource can adjust its output to provide frequency support or stabilization in response to frequency deviations with a droop of 5% or better	MISO provides market construct under normal conditions, but preferable that NIPSCO possess the ability to maintain operation during under-frequency conditions in emergencies
5	VAR Support	The resource can be used to deliver VARs out onto the system or absorb excess VARs and so can be used to control system voltage under steady-state and dynamic/transient conditions. The resource can provide dynamic reactive capability (VARs) even when not producing energy. The resource must have Automatic voltage regulation (AVR) capability. The resource must have the capability ranging from 0.85 lagging (producing) to 0.95 leading (absorbing) power factor	NIPSCO must retain resources electrically close to load centers to provide this attribute in accordance with NERC and IEEE Standards
6	Geographic Location Relative to Load	The resource will be located in NIPSCO's footprint (electric Transmission Operator Area) in Northern Indiana near existing NIPSCO 138kV or 345kV facilities and is not restricted by fuel infrastructure. The resource can be interconnected at 138kV or 345kV. Preferred locations are ones that have multiple power evacuation/deliverability paths and are close to major load centers.	MISO requires location capacity resources and runs an LMP market to provide locational energy signals; under emergency restoration procedures, a blackstart plan reliant on external resources would create a significant risk. Location provides economic value in the form of reduced losses, congestion, curtailment risk, and address local capacity requirements. Additionally, from a reliability perspective, resources that are interconnected to buses with multiple power evacuation paths and those close to load centers are more resilient to transmission system outages and provide better assistance in the blackstart restoration process.
7	Predictability and Firmness of Supply	Ability to predict/forecast the output of resources and to counteract forecast errors.	Energy is scheduled with MISO in the day-ahead hourly market and in the real-time 5-minute market. Deviations from these schedules have financial consequences and thus the ability to accurately forecast the output of a resource up to 38 hours ahead of time for the day-ahead market and 30 minutes for the real time market is advantageous.
8	Short Circuit Strength Requirement	Ensure the strength of the system to enable the stable integration of all inverter-based resources (IBRs) within a portfolio.	The retirement of synchronous generators within NIPSCO footprint and also within MISO and replacements with increasing levels of inverter-based resources will lower the short circuit strength of the system. Resources than can operate at lower levels of SCR and those that provide higher short circuit current provide a better future proofing without the need for expensive mitigation measures.

Reliability Metrics

	Criteria	Measurement Approach	Included in Minimum Interconnection Requirements	Quanta Analysis to Support Metric
1	Blackstart	• MWs with blackstart capability	NO	• Blackstart Analysis
2	Energy Adequacy	• Percentage of NIPSCO's critical load (MW and Time) that can be supplied during emergencies	NO	• Energy Adequacy Analysis
3	Dispatchability and Automatic Generation Control	• MWs on AGC • Up Range / Down range • Ability for Fast Regulation • Duration of Up / Down Regulation	NO (except being on SCADA for monitoring and control)	• Increase of Regulation Requirements due to IBRs in each Portfolio • 10-min Ramp Capability of Portfolio
4	Operational Flexibility and Frequency Support	• Inertial Response Gap/Surplus • Primary Frequency Response Gap/Surplus	NO	• Inertial Repose • Primary Response
5	VAR Support	• Continuous VAR output range that can be delivered to load centers	YES	• Dynamic VAR deliverability
6	Geographic Location Relative to Load	• MWs or % within NIPSCO footprint • Firmness of fuel supplies • MWs with POIs with multiple (2 or higher) secure power evacuation paths	NO	• Topology analysis
7	Predictability and Firmness of Supply	• Ability to mitigate Forecast Error of intermittent resources using fast ramping capability	NO	• Power Ramping and Forecast Errors
8	Short Circuit Strength Requirement	• MWs of IBRs potentially impacted by lack of short circuit strength • Need for synchronous condensers and/or grid forming inverters to ensure stable system integration	NO, 1547 and P2800 do not address	• Short Circuit Strength Analysis

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Portfolio Reliability Metrics and Measures

	Year 2030		A	B	C	D	E	F	G	H	I
1	Blackstart	Qualitative Assessment of Risk of not Starting	25%	0%	75%	25%	50%	100%	25%	50%	100%
2	Energy Adequacy	Load Growth not Served during system Emergency (avg %)	10%	2%	2%	21%	2%	3%	26%	3%	2%
		Energy Not Served when Islanded (Worst 1-week) %	76%	79%	32%	75%	78%	56%	74%	73%	58%
3	Dispatchability and Automatic Generation Control	Dispatchable (%CAP, unavoidable VER Penetration)	28%	18%	55%	27%	44%	45%	26%	47%	47%
			58%	45%	42%	63%	50%	45%	65%	51%	51%
		Increased Freq Regulation Requirements (MW)	54	37	34	58	41	37	59	46	46
		1-min Ramp Capability (MW)	331	196	261	331	666	382	326	761	599
		10-min Ramp Capability (MW)	574	439	764	574	909	784	548	983	944
4	Operational Flexibility and Frequency Support	Inertia MVA-s	3,218	3,218	6,729	3,218	3,218	5,116	2,931	2,931	4,397
		Inertial Gap FFR MW	155	277	157	160	0	79	171	0	0
		Primary Gap PFR MW	259	387	380	260	0	249	261	0	19
5	VAR Support	Dynamic VAR to load Center Capability (MVAr)	658	414	514	704	630	568	725	731	724
6	Location	Average Number of Evacuation Paths	5.0	3.0	5.5	4.6	4.7	5.2	4.8	5.6	5.2
7	Predictability and Firmness	Ramping Capability to Mitigate Forecast Errors (+Excess/-Deficit) MW	-93	-146	198	-122	296	289	-131	380	373
8	Short Circuit Strength	Required Additional Synch Condensers MVA (Stand-alone Storage with GFM inverters)	580	260	0	763	341	0	802	488	257

CAP: the capacity value of the portfolio including the existing and planned resources
Solar capacity credit : 50% of installed capacity; Wind capacity credit : 16.3% (based on MISO published data on system wide capacity credits)

Portfolio Reliability Metrics and Measures (Normalized)

	Year 2030		A	B	C	D	E	F	G	H	I
1	Blackstart	Qualitative Assessment of Risk of not Starting	25%	0%	75%	25%	50%	100%	25%	50%	100%
2	Energy Adequacy	Load Growth not Served during system Emergency (avg %)	10%	2%	2%	21%	2%	3%	26%	3%	2%
		Energy Not Served when Islanded (Worst 1-week) %	76%	79%	32%	75%	78%	56%	74%	73%	58%
3	Dispatchability and Automatic Generation Control	Dispatchable (%CAP, unavoidable VER penetration%)	28%	18%	55%	27%	44%	45%	26%	47%	47%
			58%	45%	42%	63%	50%	45%	65%	51%	51%
		Increased Freq Regulation Requirement (% Peak Load)	2.3%	1.6%	1.5%	2.5%	1.8%	1.6%	2.6%	2.0%	2.0%
		1-min Ramp Capability (%CAP)	24.0%	22.6%	17.8%	22.8%	47.2%	29.4%	22.1%	49.3%	39.0%
		10-min Ramp Capability (%CAP)	41.7%	50.7%	52.1%	39.6%	64.4%	60.3%	37.1%	63.7%	61.5%
4	Operational Flexibility and Frequency Support	Inertia (s)	2.13	3.38	4.17	2.02	2.07	3.58	1.81	1.73	2.60
		Inertial Gap FFR (%CAP)	11.2%	32.1%	10.7%	11.0%	0.0%	6.1%	11.6%	0.0%	0.0%
		Primary Gap PFR (%CAP)	18.8%	44.7%	25.9%	17.9%	0.0%	19.1%	17.7%	0.0%	1.3%
5	VAR Support	Dynamic VAR to load Center Capability (%CAP)	47.8%	47.8%	35.1%	48.5%	44.7%	43.6%	49.1%	47.4%	47.1%
6	Location	Average Number of Evacuation Paths	5	2.5	N/A	4.6	4.7	4.7	4.8	5.6	5.1
7	Predictability and Firmness	Ramping Capability to Mitigate Forecast Errors (+Excess/-Deficit) (%VER MW)	-4.1%	-8.0%	11.4%	-5.0%	14.9%	15.8%	-5.3%	17.4%	17.1%
8	Short Circuit Strength	Required Additional Synch Condensers (%Peak Load)	25%	11%	0%	33%	15%	0%	35%	21%	11%

VER: Variable Energy Resources (e.g., solar, wind)

CAP: Capacity credit of all resources including existing, planned, and portfolio

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Scoring Criteria Thresholds

	Year 2030		1 (Pass)	2 (Caution)	3 (Problem)	Rationale
1	Blackstart	Ability to blackstart using Storage & Synchronous Condensers	>50%	25-50%	<25%	System requires real and reactive power sources with sufficient rating to start other resources. Higher rated resources lower the risk
2	Energy Adequacy	Energy not Served during market emergencies (% of load consumption increase)	<5%	5-20%	>20%	Ability of portfolio resources to serve unanticipated growth in load consumption during MISO emergency max-gen events.
		Energy Not Served when Islanded (Worst 1-week) %	<70%	70-85%	>85%	Ability of Resources to serve critical loads for 1 week, estimated at 15% of total load. Adding other important loads brings the total to 30%
3	Dispatchability	Dispatchable (VER Penetration %)	<50%	50-60%	>60%	Intermittent Power Penetration above 60% is problematic when islanded
		Increased Freq Regulation Requirements	<2% of peak load	2-3% of Peak Load	>3% of peak load	Regulation of Conventional Systems ≈1%
		1-min Ramp Capability	>15% of CAP	10-15% of CAP	<10% of CAP	10% per minute was the norm for conventional systems. Renewable portfolios require more ramping capability
		10-min Ramp Capability	>65% of CAP	50-65% of CAP	<50% of CAP	10% per minute was the norm for conventional systems. But with 50% min loading, that will be 50% in 10 min. Renewable portfolios require more ramping capability
4	Operational Flexibility and Frequency Support	Inertia (seconds)	>3xMVA rating	2-3xMVA rating	<2xMVA rating	Synchronous machine has inertia of 2-5xMVA rating.
		Inertial Gap FFR (assuming storage systems will have GFM inverters)	0	0-10% of CAP	>10% of CAP	System should have enough inertial response, so gap should be 0. Inertial response of synch machine ≈ 10% of CAP
		Primary Gap PFR MW	0	0 - 2% of CAP	2% of CAP	System should have enough primary response, so gap should be 0. Primary response of synch machine ≈ 3.3%of CAP/0.1Hz (Droop 5%)
5	VAR Support	VAR Capability	≥41% of ICAP	31-41% of ICAP	<31% of ICAP	Power factor higher than 95% (or VAR less than 31%) not acceptable. Less than 0.91 (or VAR greater than 41.5%) is good
6	Location	Average Number of Evacuation Paths	>3	2-3	<2	More power evacuation paths increases system resilience
7	Predictability and Firmness	Ramping Capability to Mitigate Forecast Errors (+Excess/-Deficit) MW	≥ 0	-10% - 0% of CAP	<-10% of CAP	Excess ramping capability to offset higher levels of intermittent resource output variability is desired
8	Short Circuit Strength	Required Additional Synch Condensers MVA	0	0-21.9% of CAP	>21.9% of CAP	Portfolio should not require additional synchronous condensers. 500MVAr is a threshold (same size as one at Babcock)

Portfolio Reliability Ranking

	Year 2030		A	B	C	D	E	F	G	H	I
1	Blackstart	Qualitative Assessment of Risk of not Starting	1/2	0	1	1/2	1/2	1	1/2	1/2	1
2	Energy Adequacy	Load Growth not Served during system Emergency (avg %)	1/2	1	1	0	1	1	0	1	1
		Energy Not Served when Islanded (Worst 1-week) %	1/2	1/2	1	1/2	1/2	1	1/2	1/2	1
3	Dispatchability and Automatic Generation Control	Dispatchable (VER Power Penetration %)	1/2	1	1	0	1/2	1	0	1/2	1/2
		Increased Freq Regulation Requirement (% Peak Load)	1/2	1	1	1/2	1	1	1/2	1/2	1/2
		1-min Ramp Capability (%CAP)	1	1	1	1	1	1	1	1	1
		10-min Ramp Capability (%CAP)	0	1/2	1/2	0	1/2	1/2	0	1/2	1/2
4	Operational Flexibility and Frequency Support	Inertia (s)	1/2	1	1	1/2	1/2	1	0	0	1/2
		Inertial Gap FFR (%CAP)	0	0	0	0	1	1/2	0	1	1
		Primary Gap PFR (%CAP)	0	0	0	0	1	0	0	1	1/2
5	VAR Support	Dynamic VAR to load Center Capability (%CAP)	1	1	1/2	1	1	1	1	1	1
6	Location	Average Number of Evacuation Paths	1	1/2	1	1	1	1	1	1	1
7	Predictability and Firmness	Ramping Capability to Mitigate Forecast Errors (+Excess/-Deficit) (%VER MW)	1/2	1/2	1	1/2	1	1	1/2	1	1
8	Short Circuit Strength	Required Additional Synch Condensers (%Peak Load)	0	1/2	1	0	1/2	1	0	1/2	1/2

		A	B	C	D	E	F	G	H	I
1	Blackstart	0.50	0.00	1.00	0.50	0.50	1.00	0.50	0.50	1.00
2	Energy Adequacy	0.50	0.75	1.00	0.25	0.75	1.00	0.25	0.75	1.00
3	Dispatchability and Automatic Generation Control	0.50	0.88	0.88	0.38	0.75	0.88	0.38	0.63	0.63
4	Operational Flexibility and Frequency Support	0.17	0.33	0.33	0.17	0.83	0.50	0.00	0.67	0.67
5	VAR Support	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00
6	Location	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	Predictability and Firmness	0.50	0.50	1.00	0.50	1.00	1.00	0.50	1.00	1.00
8	Short Circuit Strength	0.00	0.50	1.00	0.00	0.50	1.00	0.00	0.50	0.50

	A	B	C	D	E	F	G	H	I
Cumulative core	4.17	4.46	6.71	3.79	6.33	7.38	3.63	6.04	6.79
Percent Score (out of possible 8)	52%	56%	84%	47%	79%	92%	45%	76%	85%
			3		4	1		5	2

1 Portfolio passes the screening test
½ Portfolio requires minor to moderate mitigation measures
0 Portfolio requires significant mitigation measures

Reliability Assessment Study

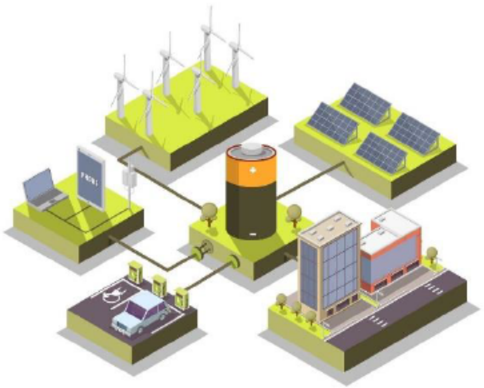
Content:

1. Essential Reliability Services - Overview
2. NIPSCO Demand and Resource Development
3. Resource Variability Analysis
4. Modeling the Portfolios:
    i. Energy Adequacy Analysis (Islanded, Emergency)
    ii. Dispatchability
    iii. Flexibility: Inertial, Primary Frequency Response
    iv. Dynamic VAR Support
    v. Predictability of Supply
    vi. Short Circuit Strength
    vii. Blackstart
    viii. Locational Attributes
5. Summary of Findings

Series of filters to Assess System Reliability

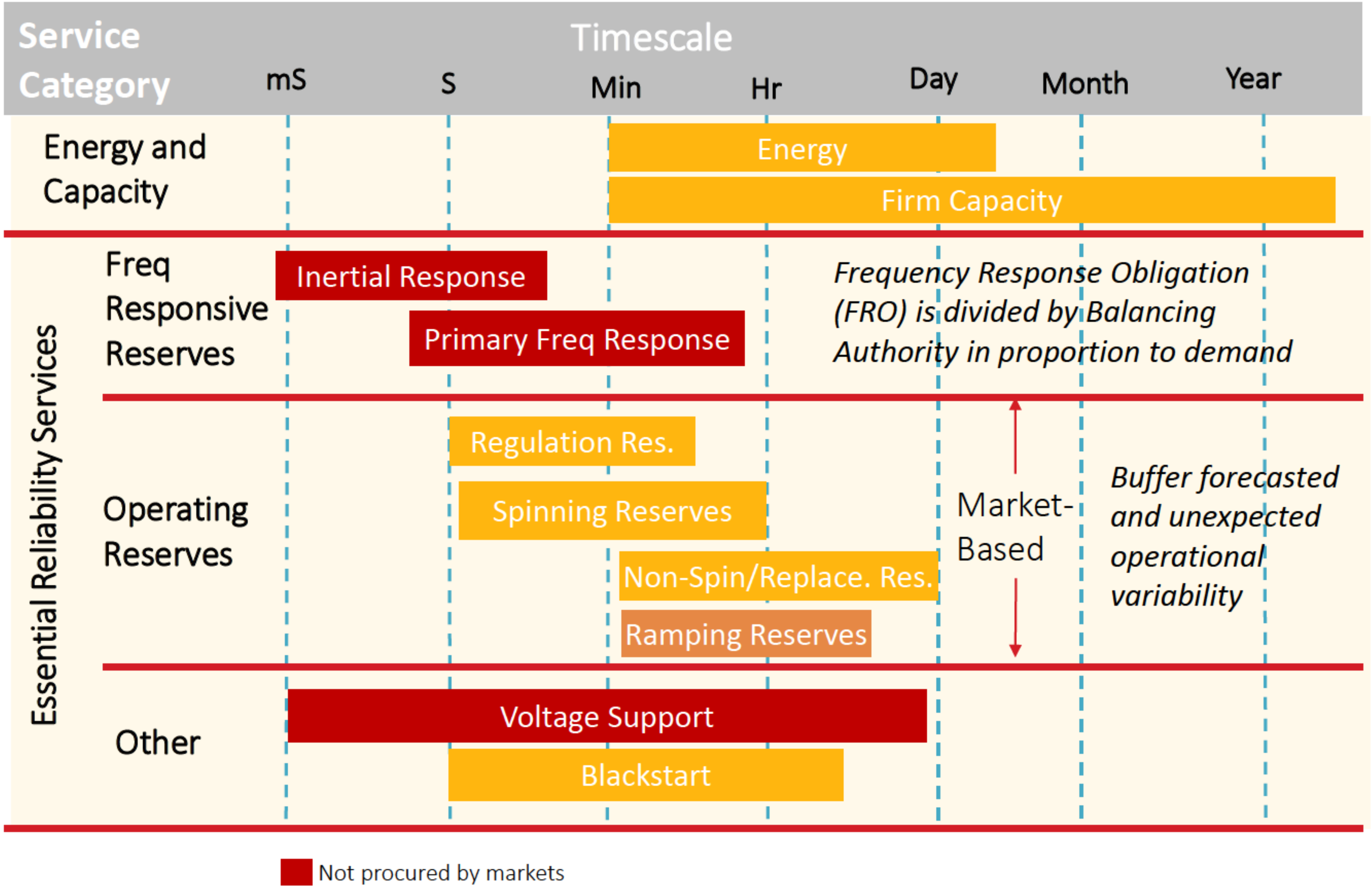
Modeling Resource Reliability Attributes

- Resources have many attributes aside from energy and capacity that are critical to reliable operation.
  - Selecting a portfolio with the right attributes is crucial to ensure reliability and resilience.
  - Valuation and ranking of portfolios should account for their reliability attributes.
  - System needs for reliability attributes increases with higher levels of inverter-based resources (IBRs).



- Reliability and Resilience Attributes/Metrics:
  - Dispatchability
  - Predictability
  - Dependability (e.g., Supply Resilience, firmness)
  - Performance Duration Limits
  - Flexibility (e.g., ramping speed, operating range)
  - Intermittency (e.g., intra-hr and multi-hr ramping)
  - Regulating Power
  - Dynamic VAR support
  - Energy Profile (e.g., capacity value / ELCC)
  - Inertial Response
  - Primary Frequency Response
  - Minimum Short Circuit Ratio
  - Locational Characteristics (e.g., deliverability, resilience to grid outages)
  - Blackstart and system restoration support
  - Flicker
  - Harmonics
  - Sub-synchronous Resonance

Essential Reliability Services



- **Regulation Reserves:**
  - Rapid response by generators used to help restore system frequency. These reserves may be deployed after an event and are also used to address normal random short-term fluctuations in load that can create imbalances in supply and demand.
- **Ramping Reserves:**
  - An emerging and evolving reserve product (also known as load following or flexibility reserves) that is used to address "slower" variations in net load and is increasingly considered to manage variability in net load from wind and solar energy. MISO sets the MW level based on the sum of the forecasted change in net load and an additional amount of ramp up/down (575 MW for now).

Essential Reliability Services - Reserve Requirements

2020	MISO	CAISO	PJM	ERCOT	ISO-NE	NYISO	SPP
Peak Demand	**121.4**	53.6	147.5	73.7	26.3	32.1	52.5
Reserve Margin %	**15.80%**	16.14%	16.60%	13.75%	16.90%	15%	12%
Peak Capacity Requirement GW	**140.6**	62.3	172	83.5	30.3	36.9	58.8
Primary Freq Response Obligation							
(MW/0.1Hz)	**210**	196.5	258.3	381	38.3	49.9	
MW	**882**	550	1085	1543	161	210	
% of Peak Load	**0.70%**	1.10%	0.70%	2.20%	0.70%	0.70%	
Regulating Reserve Requirement							
Up/Down %	**0.35%**	0.64%/0.72%	0.36% offpeak; 0.55% on-peak	0.48%/0.42%	0.25%	0.73%	0.92%/0.63%
Up/Down MW	**425**	320/360	525/800	318/295	60	217	470/325
Spinning Reserve							
%	**0.61%**	1.60%	1.03%	3.76%	3.75%	2.20%	1.14%
MW	**740**	800	1504.8	2626.8	900.00	655	585
Non-Spinning Reserve							
%	**0.92%**	1.60%	1.03%	2.21%	10min 5.98% ; 30min 3.33%	10min 4.41%, 30min 8.82%	1.43%
MW	**1110**	800	1053.2	1534.5	1435/800	1310/2620	730
Ramping Reserve Requirement							
5 min MW		-300/500					
15 min MW		-1200/1800					
Hourly MW	**-1614/1554**						

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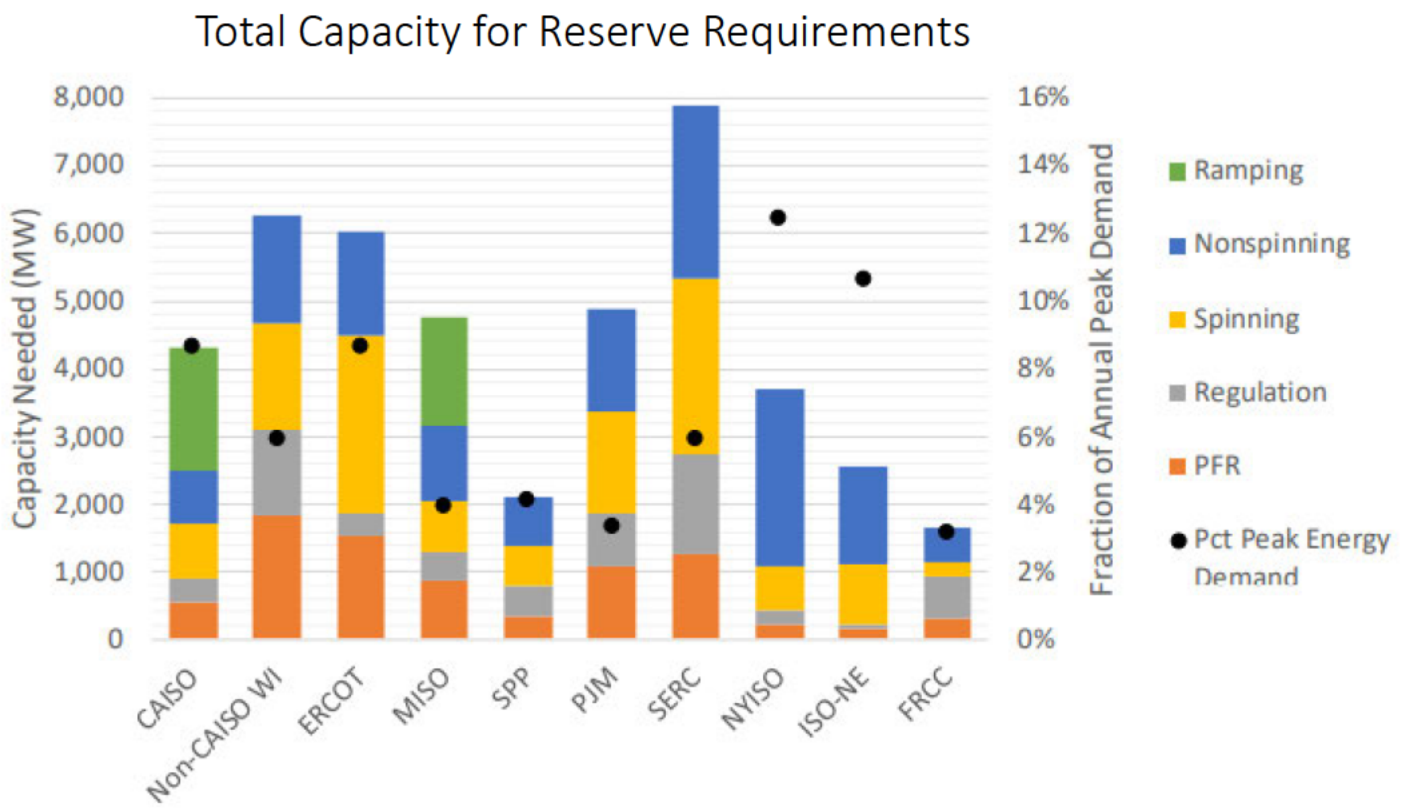
Essential Reliability Services



- MISO's total capacity for reserves is around 4% of peak load. This is comparable to PJM and SPP. However, is less than half of CAISO, NYISO, ERCOT, and ISO-NE.
- MISO has a ramping product.

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Reliability Concerns of high Penetration Inverter-Based Resources (IBRs)

Key Consideration	System Concern
Power Ramping	• High Up and Down Intermittent "un-forecasted" Power Ramps can affect Control Area performance
Low System Inertia	• High RoCoF following a large loss causes resources to trip due to reduced synchronizing torques • Under Frequency relays respond to low frequency (nadir) by tripping load • Speed of system events faster than ability of protection system
Low Short Circuit Ratio (Weakened Grid)	• Instability in inverter controls (PLL synchronization and inner current loop low frequency oscillations) • Challenges to inverter Ride-Through and Islanding • Voltage Flicker (especially in distribution feeders) • Difficulty of voltage control due to high voltage sensitivity dV/dQ • Difficulty in energizing large power transformers
Low Fault Current Levels	• Ability of protection systems to detect faults
Low damping of system oscillations	• Synchronous machines have rotor dampers. • Use of grid forming inverters and inverter control settings to mitigate
Low Reserves	• Renewables operate at max power tracking and do not leave a headroom for reserves
Flicker	• Intermittent renewables cause fluctuations is system voltages especially when the grid short circuit strength is low. Ensure compliance with IEEE 1453 standard for flicker.
Blackstart	• Ability to restart a system with predominantly inverter-based resources.

1

Impact of Inverter Based Generation onto Protection System

- **Declining Inertia of the power system**
  - The frequency change is important in regard to the stability of protective relays during power swing conditions.
  - In more extreme cases of system frequency changes, it may even impact the protection relay algorithms to a degree that an over or under frequency event can be erroneously caused.
  - The requirements onto maximum fault clearing time are a function of the system inertia
- **Reduced short circuit current (fault level)**
  - The inverter-based fault current contribution to short circuits is limited by the electronic controls of the inverters. The level may vary between control designs but would typically be in the order of 1.0 – 1.5 times nominal current. This will cause sensitivity issues for protective relays where they may fail to operate, or their operation will not be properly coordinated.
- **Different negative sequence fault current contribution**
  - Inverter contribution of negative- or zero-sequence current to a fault depend to inverter type and generation. Protection schemes that rely on negative sequence current are impacted. (directional elements, over current elements)
- **Changed source impedance characteristic**
  - The source impedance of an inverter-based generator during a fault is determined by the control algorithm of the inverter and does not need to be inductive. This may affect and challenge correct operation of the cross- or memory polarisation functions of protection relays.
- **Missing model of inverter-based generation**
  - The characteristic of inverters is mostly determined by the control algorithm selected and developed by the manufacturer. The behaviour of inverters from different manufacturers can be different in response to the fault current. the correct modelling of inverter-based generation inside of short circuit programs used for protection studies is challenging. This is even more a challenge for aggregated inverter-based generation that's consist of different power sources like wind generation type 3, type 4 or solar panels.

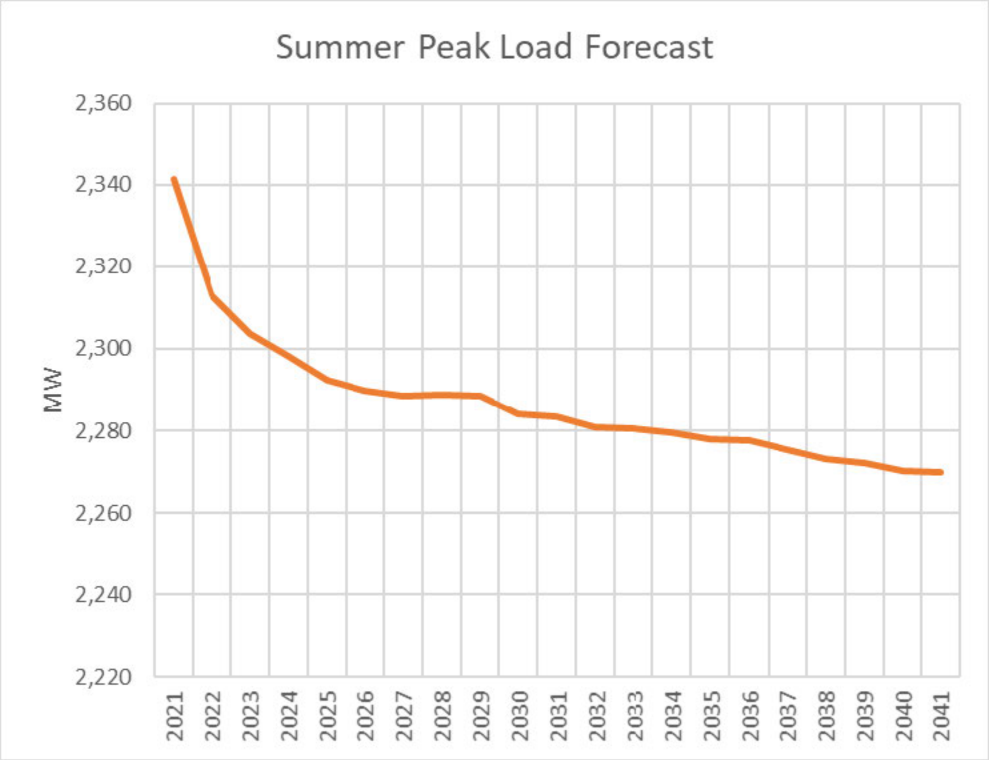
Reliability Assessment Study

Content:

Series of filters to Assess System Reliability

Base Load Forecast

Year	Baseline Summer Peak
2021	2,341
2022	2,313
2023	2,304
2024	2,298
2025	2,292
2026	2,290
2027	2,289
2028	2,289
2029	2,289
2030	2,284
2031	2,283
2032	2,281
2033	2,281
2034	2,279
2035	2,278
2036	2,277
2037	2,275
2038	2,273
2039	2,272
2040	2,270
2041	2,270

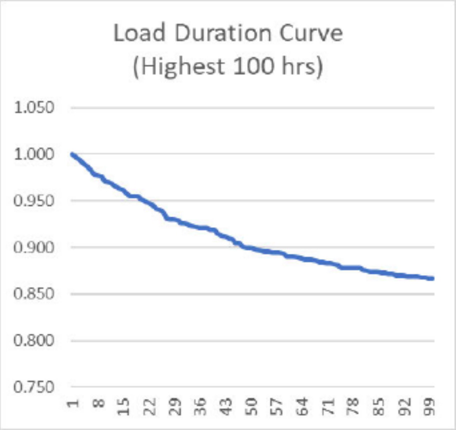


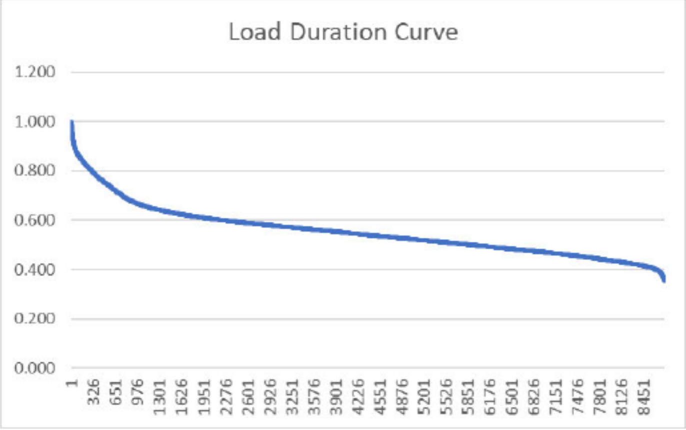
- NIPSCO system delivers energy within its service territory to a total demand of 3500MW, of which:
  - 2350 MW NIPSCO baseload (net of DR and EE initiatives)
  - 700 MW NIPSCO Rate 831 Customers
  - 450 MW Wholesale (IMPA & WVPA)
- NIPSCO Rate 831 & Wholesale customers arrange their supplies directly.
- The IRP is focused on the NIPSCO baseload customers only.

Demand Profile

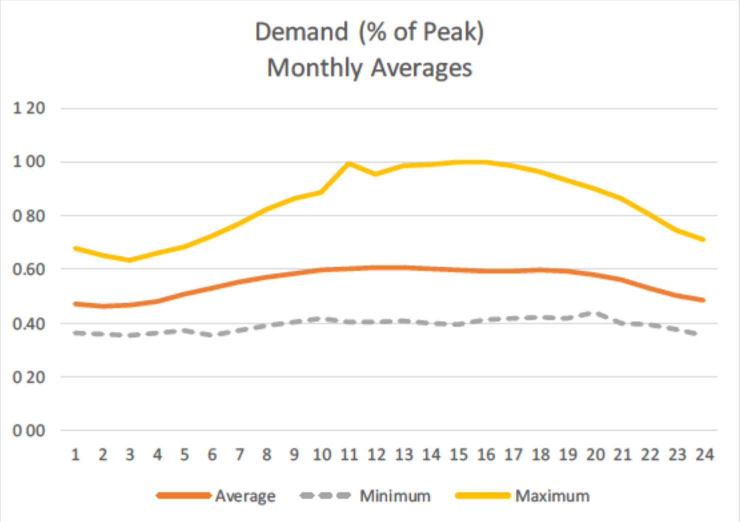
Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0.50	0.50	0.50	0.50	0.52	0.55	0.58	0.58	0.59	0.60	0.60	0.59	0.59	0.58	0.57	0.57	0.57	0.60	0.60	0.59	0.58	0.56	0.54	0.52
2	0.49	0.49	0.49	0.49	0.52	0.55	0.57	0.58	0.59	0.59	0.59	0.58	0.58	0.57	0.56	0.55	0.56	0.58	0.58	0.58	0.57	0.55	0.52	0.50
3	0.46	0.46	0.47	0.49	0.51	0.54	0.55	0.56	0.56	0.56	0.55	0.55	0.54	0.52	0.51	0.51	0.51	0.52	0.55	0.53	0.52	0.49	0.48	0.47
4	0.43	0.43	0.44	0.46	0.49	0.51	0.53	0.54	0.54	0.54	0.54	0.54	0.52	0.51	0.51	0.50	0.49	0.50	0.51	0.51	0.50	0.47	0.45	0.44
5	0.42	0.42	0.43	0.44	0.47	0.50	0.52	0.54	0.54	0.55	0.55	0.55	0.55	0.54	0.53	0.52	0.52	0.52	0.52	0.52	0.49	0.47	0.44	0.43
6	0.46	0.45	0.45	0.47	0.48	0.51	0.53	0.56	0.58	0.60	0.62	0.63	0.64	0.64	0.64	0.63	0.62	0.61	0.60	0.59	0.57	0.53	0.50	0.47
7	0.55	0.53	0.53	0.54	0.56	0.58	0.62	0.66	0.71	0.74	0.77	0.79	0.81	0.82	0.82	0.82	0.81	0.79	0.76	0.74	0.70	0.65	0.60	0.57
8	0.51	0.49	0.50	0.51	0.54	0.56	0.59	0.62	0.65	0.68	0.71	0.73	0.75	0.75	0.76	0.76	0.75	0.72	0.70	0.68	0.64	0.60	0.56	0.53
9	0.46	0.46	0.46	0.48	0.51	0.53	0.55	0.57	0.59	0.61	0.63	0.64	0.66	0.66	0.66	0.66	0.65	0.64	0.64	0.61	0.59	0.54	0.51	0.48
10	0.43	0.43	0.44	0.46	0.49	0.52	0.54	0.55	0.55	0.55	0.55	0.56	0.55	0.54	0.53	0.53	0.53	0.54	0.54	0.53	0.50	0.48	0.45	0.44
11	0.46	0.46	0.46	0.47	0.50	0.52	0.54	0.55	0.56	0.56	0.56	0.55	0.55	0.54	0.53	0.53	0.54	0.55	0.55	0.54	0.53	0.50	0.48	0.47
12	0.48	0.47	0.47	0.47	0.49	0.52	0.55	0.56	0.56	0.56	0.56	0.55	0.55	0.55	0.54	0.54	0.56	0.57	0.57	0.57	0.56	0.54	0.51	0.49
Average	*0.47*	*0.47*	*0.47*	*0.48*	*0.51*	*0.53*	*0.56*	*0.57*	*0.59*	*0.60*	*0.60*	*0.61*	*0.61*	*0.60*	*0.60*	*0.59*	*0.59*	*0.60*	*0.59*	*0.58*	*0.56*	*0.53*	*0.50*	*0.48*
Minimum	*0.36*	*0.36*	*0.35*	*0.36*	*0.37*	*0.36*	*0.37*	*0.39*	*0.41*	*0.42*	*0.40*	*0.40*	*0.41*	*0.40*	*0.40*	*0.41*	*0.42*	*0.42*	*0.42*	*0.44*	*0.40*	*0.40*	*0.38*	*0.36*
Maximum	*0.68*	*0.65*	*0.64*	*0.66*	*0.68*	*0.72*	*0.77*	*0.82*	*0.87*	*0.89*	*0.99*	*0.95*	*0.98*	*0.99*	*1.00*	*1.00*	*0.99*	*0.96*	*0.93*	*0.90*	*0.86*	*0.80*	*0.75*	*0.71*

- The demand is Summer peaking (July), and peak hours are mid day (11AM-4PM).
- Highest 15% of peak demand occurs in only 100 hours in a year.





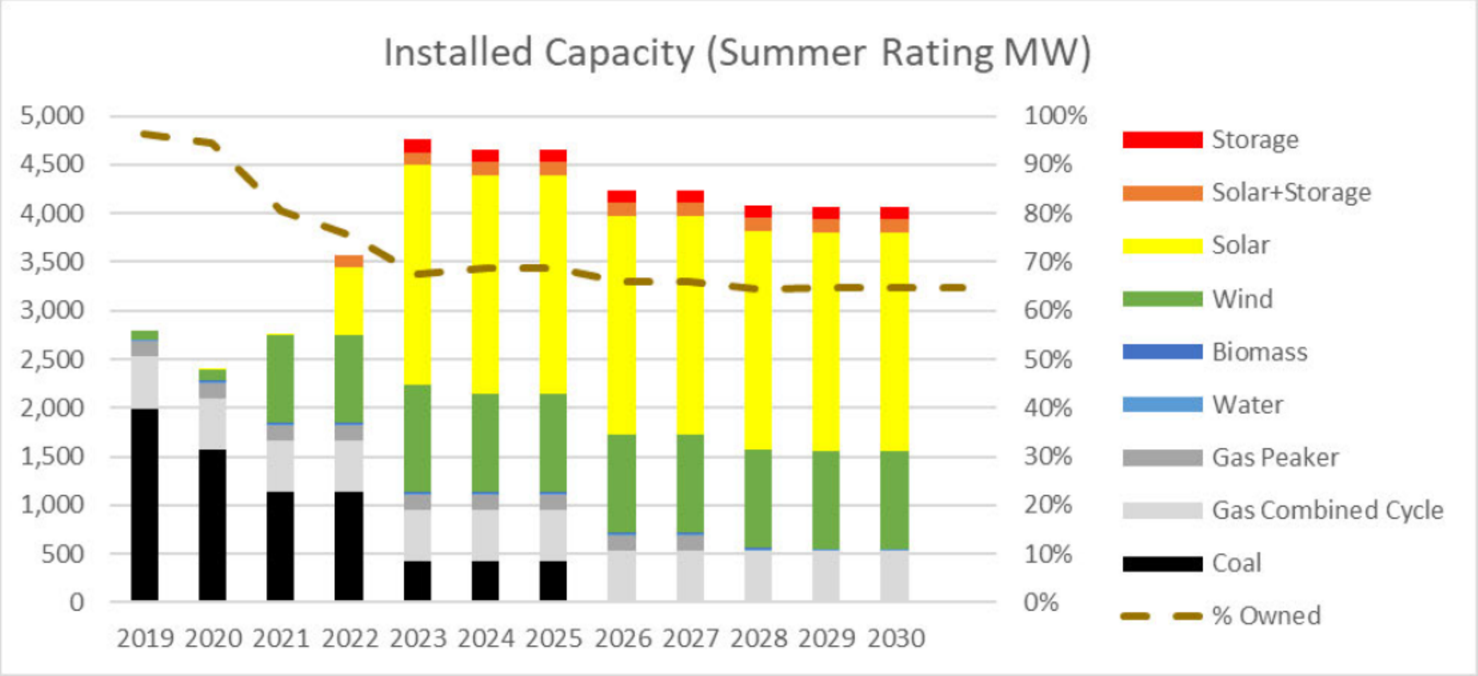
Month	Monthly Consumption (% of Max)
1	88%
2	80%
3	75%
4	72%
5	73%
6	81%
7	100%
8	93%
9	84%
10	74%
11	76%
12	78%



Annual Consumption pu-h 4,849
Load Factor 55.4%

Existing and Planned Generation Resources

- **Existing Resources** (2019)
  - Coal 1,995 MW
  - Combined Cycle 535 MW
  - Gas Peaker 155 MW
  - Water 10 MW
  - Wind PPA 100 MW
  - 2,795 MW
- **Planned Resource Additions**
  - Wind (2021/2023) 1,005 MW
  - Solar (2020/2022/2023) 2,254 MW
  - Solar+Storage (2022) 130 MW
  - Storage (2023) 135 MW
  - 3,524 MW
- **End of Life Schedule:**
  - Coal (2020-2028) 1,995 MW
  - Gas Peaker (2028) 155 MW
  - Wind PPA (2024) 100 MW
  - 2,250 MW



- Significant changes in the resource mix are already planned prior to the 2021 IRP results, with a significant shift away from Coal towards Solar and Wind resources.
- The percentage ownership by NIPSCO decreases as more PPAs/FIT resources are contracted to reach 65% in 2028.

2021 IRP - Considered Portfolios

Resource	Year	A	B	C	D	E	F	G	H	I	Resource End Date
Sugar Creek Uprate	2027	53	53	53	53	53	53	0	0	53	
New DER	2026	10	10	10	10	10	10	10	10	10	
Wind P1	2026	0	0	0	0	0	0	0	200	200	
Solar P2	2026	250	100	0	400	250	100	450	250	250	
Solar+Storage P1	2026	450	0	0	450	0	0	450	0	0	
Storage P2	2025	0	0	0	0	0	0	0	100	100	
Storage P2	2026	0	0	0	0	100	0	0	100	0	
Storage P2	2027	0	0	0	0	100	0	0	100	0	
Storage A2	2025	0	0	0	0	135	0	0	135	135	
Storage A2	2026	0	0	0	0	0	0	0	0	0	
Storage A2	2027	135	0	0	135	135	135	135	135	135	
Gas Peaking P1	2026	0	443	0	0	0	0	0	0	0	
Gas Peaking A1	2026	0	0	0	0	0	300	0	0	0	
Gas CC A1	2026	0	0	650	0	0	0	0	0	0	
Other Thermal P1	2024	50	50	0	0	50	50	0	0	0	2034
Other Thermal P2	2026	100	100	0	0	100	100	0	0	0	2036
Hydrogen P1	2025	0	0	0	0	0	0	0	0	193	
Hydrogen P2	2026	0	0	0	0	0	0	0	0	20	

- Retirements:
  - Schahfer 17/18 2023
  - MC12 Retirement 2026
- Other Thermal P1, P2:
  - A hedge, and resources are outside of NIPSCO's footprint

Emissions	Current Planning Reserve Margin	Winter & Summer Reserve Margin	Enhanced Reserve Margin (Local w/ Higher Duration)
Higher Carbon Emissions	**A** 1,048 NIPSCO DER 10MW SC Uprate 53MW Thermal PPA 150MW Storage 135MW Solar+Storage 450MW* Solar 250MW	**B** 906 NIPSCO DER 10MW SC Uprate 53MW Gas Peaker** 443MW Thermal PPA 150MW Solar 250MW	**C** 713 NIPSCO DER 10MW SC Uprate 53MW Gas CC 650MW
Mid Carbon Emissions	**D** 1,048 NIPSCO DER 10MW SC Uprate 53MW Storage 135MW Solar+Storage 450MW* Solar 400MW	**E** 933 NIPSCO DER 10MW SC Uprate 53MW Thermal PPA 150MW Storage 470MW Solar 250MW	**F** 748 NIPSCO DER 10MW SC Uprate 53MW Gas Peaker** 300MW Thermal PPA 150MW Storage 135MW Solar 100MW
Low Carbon Emissions	**G** 1,045 NIPSCO DER 10MW Storage 135MW Solar+Storage 450MW* Solar 450MW	**H** 1,030 NIPSCO DER 10MW Wind 200MW Storage 570MW Solar 250MW	**I** 1,076 NIPSCO DER 10MW SC H2 Electrolyzer 20MW SC Uprate 53MW H2 Enabled Peaker 193MW Wind 200MW Storage 370MW Solar 250MW

**Gas Peaker: Local to Service Territory in Portfolio F, while outside of territory in Portfolio B

- The IRP assumes the retirement of existing peaker units at Schahfer and Coal plant at Michigan City ahead of their end-of-life schedules, including their associated transmission upgrades.
- Due to the expected migration of MISO to a monthly/seasonal reserve requirement model, and the overall societal push to a lower carbon future, Portfolios E, F, H, I are the key focus of this reliability study.

Resources in Y2030

- 2,150 MW of conventional resources will be retired.
- 3,424 MW of IBR resources are planned to be added.
- Portfolios A through I will provide additional resources. The total of all resources in 2030 are summarized below. The mix of IBRs among all resources ranges between 74% to 89%.

All Resources – Owned and Contracted, Inside and Outside of NIPSCO's Service Area

Portfolio	Solar PV MW	Wind MW	Energy Storage MW	Thermal Gen MW	Hydro MW	IBR %
A	2,890	1,006	463	738	10	85%
B	2,440	1,006	178	1,181	10	75%
C	2,340	1,006	178	1,238	10	74%
D	3,040	1,006	463	588	10	88%
E	2,590	1,006	648	738	10	85%
F	2,440	1,006	313	1,038	10	78%
G	3,090	1,006	463	535	10	89%
H	2,590	1,206	748	535	10	89%
I	2,590	1,206	548	801	10	84%

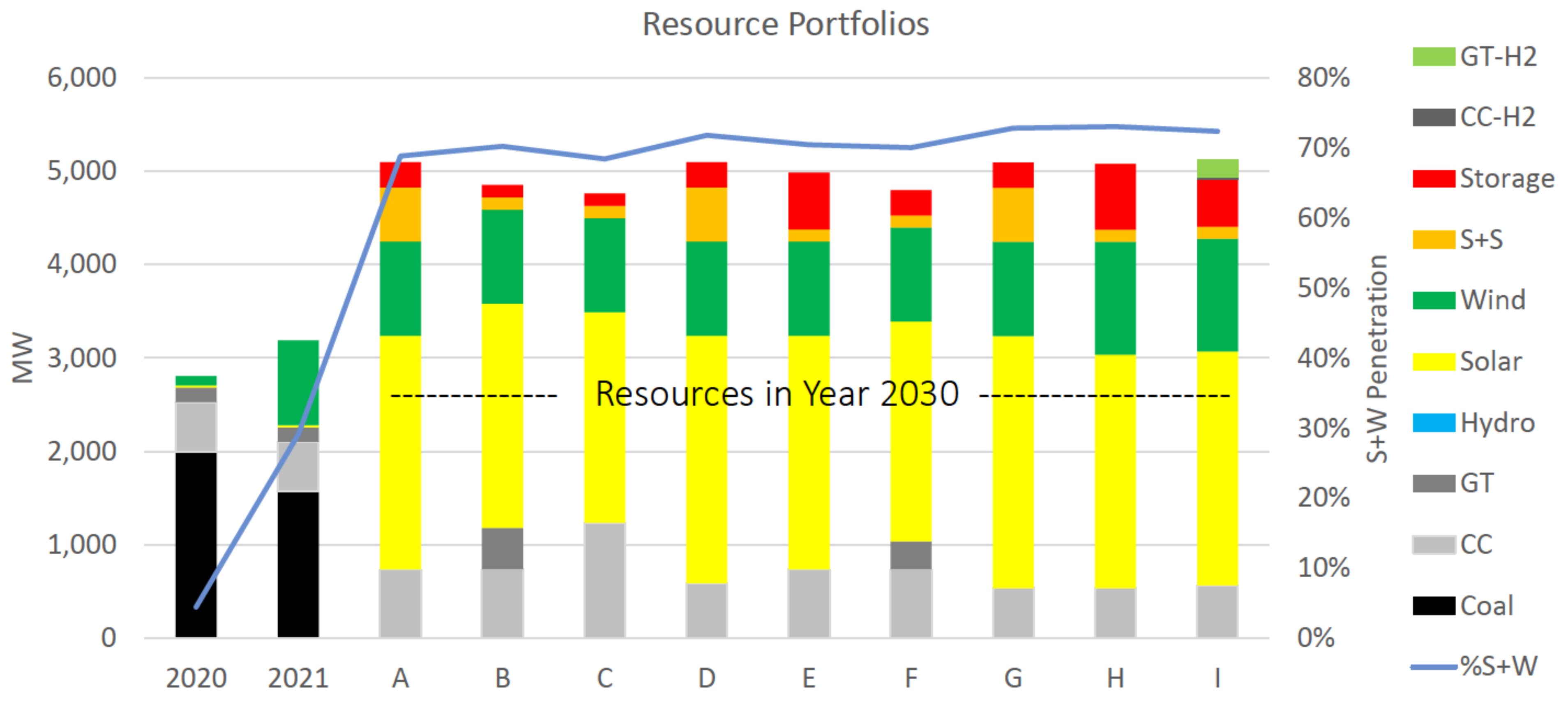
Solar+Storage resources are assumed to be 2/3 solar PV and 1/3 storage

All Resources – Owned and Contracted, Inside of NIPSCO's Service Area Only

Portfolio	Solar PV MW	Wind MW	Energy Storage MW	Thermal Gen MW	Hydro MW	IBR %
A	1,674	606	420	0	10	99.6%
B	1,224	606	135	0	10	99.5%
C	1,124	606	135	650	10	73.9%
D	1,824	606	420	0	10	99.7%
E	1,374	606	605	0	10	99.6%
F	1,224	606	270	300	10	87.1%
G	1,874	606	420	0	10	99.7%
H	1,374	806	705	0	10	99.7%
I	1,374	806	505	193	10	93.0%

IRP Portfolios

All Portfolios (A-I) will transition the system from
96% dispatchable portfolio in 2019 to over 68% intermittent by 2030, while
Renewable Penetration will increase from 3% to 76%-90%



RE Penetration	3%	26%	86%	79%	76%	89%	81%	78%	90%	87%	87%

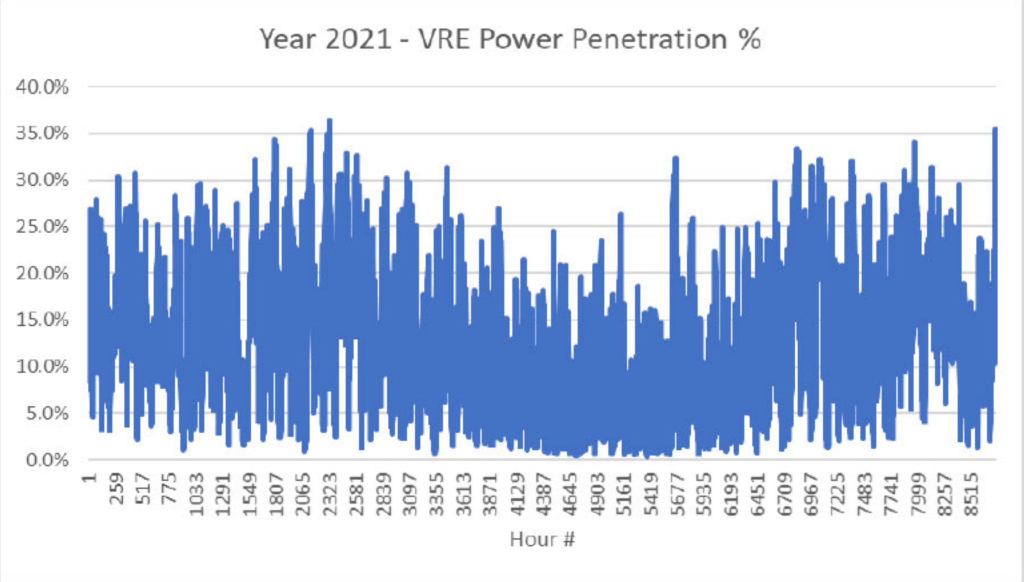
Resource Development

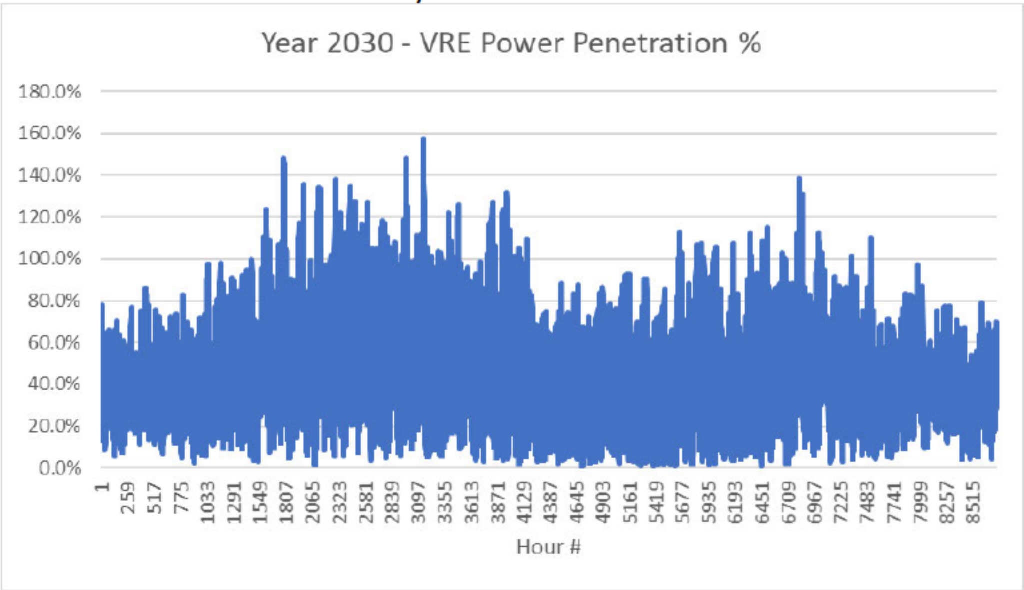
			2030								
	2020	**2021**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Coal	1,995	1,570	0	0	0	0	0	0	0	0	0
CC	535	535	738	738	1,238	588	738	738	535	535	568
GT	155	155	0	443	0	0	0	300	0	0	0
Hydro	0	0	0	0	0	0	0	0	0	0	0
Solar	24	24	2,504	2,404	2,254	2,654	2,504	2,354	2,704	2,504	2,504
Wind	101	906	1,006	1,006	1,006	1,006	1,006	1,006	1,006	1,206	1,206
Solar+Storage	0	0	580	130	130	580	130	130	580	130	130
Storage	0	0	270	135	135	270	605	270	270	705	505
CC-H2	0	0	0	0	0	0	0	0	0	0	20
GT-H2	0	0	0	0	0	0	0	0	0	0	193
Total	2,810	3,190	5,098	4,856	4,763	5,098	4,983	4,798	5,095	5,080	5,126
Solar+Wind %	4%	29%	69%	70%	68%	72%	70%	70%	73%	73%	72%
RE Penetration %	3%	26%	86%	79%	76%	89%	81%	78%	90%	87%	87%

All Resources – Owned and Contracted, Inside and Outside of NIPSCO's Service Area

Power Penetration Level by Intermittent Resources

Portfolio E – Resources inside NIPSCO service Area Only





Average VRE Power Penetration %									Hour Ending																		
Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Avg	Min	Max
1	18%	19%	18%	18%	17%	16%	16%	16%	16%	14%	13%	13%	13%	12%	13%	13%	13%	13%	14%	15%	16%	16%	17%	18%	15%	2%	31%
2	17%	17%	17%	17%	16%	15%	14%	13%	12%	11%	10%	10%	10%	10%	11%	12%	12%	11%	13%	13%	14%	14%	15%	17%	13%	1%	30%
3	18%	18%	18%	17%	16%	15%	14%	13%	12%	11%	11%	11%	12%	13%	13%	14%	14%	14%	13%	13%	14%	16%	17%	17%	14%	1%	35%
4	20%	20%	20%	19%	18%	17%	16%	15%	14%	13%	13%	14%	14%	14%	14%	15%	15%	15%	14%	14%	15%	17%	18%	20%	16%	1%	36%
5	16%	16%	15%	15%	14%	14%	12%	9%	9%	9%	9%	10%	10%	11%	11%	11%	12%	12%	12%	12%	13%	14%	15%	15%	12%	1%	31%
6	12%	13%	14%	12%	12%	11%	9%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	8%	9%	8%	8%	9%	10%	11%	9%	1%	27%
7	11%	12%	11%	11%	11%	10%	8%	6%	4%	4%	3%	3%	3%	3%	3%	3%	4%	4%	4%	4%	5%	6%	8%	10%	6%	0%	24%
8	10%	10%	11%	11%	10%	10%	8%	8%	4%	3%	3%	3%	3%	3%	4%	5%	5%	5%	6%	6%	7%	8%	9%	10%	7%	0%	32%
9	13%	13%	13%	12%	12%	11%	10%	9%	8%	6%	5%	6%	6%	6%	6%	6%	6%	7%	7%	7%	8%	10%	12%	12%	9%	1%	25%
10	21%	20%	19%	18%	17%	16%	15%	14%	12%	11%	11%	11%	12%	12%	13%	13%	12%	12%	12%	12%	15%	17%	18%	19%	15%	1%	33%
11	19%	19%	17%	17%	15%	14%	14%	15%	14%	13%	12%	12%	11%	11%	12%	12%	12%	12%	14%	15%	16%	18%	19%	19%	15%	1%	34%
12	17%	17%	17%	17%	16%	15%	14%	14%	14%	13%	13%	13%	12%	12%	12%	12%	12%	12%	13%	14%	15%	16%	17%	18%	14%	1%	35%
Average	16%	16%	16%	15%	14%	14%	13%	12%	10%	10%	9%	9%	9%	10%	10%	10%	10%	10%	11%	11%	12%	13%	15%	16%			

Average VRE Power Penetration %									Hour Ending																		
Month/Hr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Avg	Min	Max
1	28%	29%	28%	27%	26%	25%	25%	27%	46%	57%	59%	60%	60%	60%	61%	56%	34%	21%	21%	23%	24%	24%	25%	27%	36%	6%	86%
2	25%	26%	26%	27%	24%	23%	21%	33%	53%	64%	68%	69%	67%	69%	71%	68%	50%	26%	19%	20%	21%	22%	24%	26%	39%	3%	98%
3	27%	28%	28%	26%	24%	23%	28%	54%	74%	83%	87%	90%	92%	93%	92%	86%	74%	43%	23%	21%	22%	24%	26%	27%	50%	1%	148%
4	31%	30%	31%	29%	28%	29%	53%	81%	90%	95%	99%	102%	104%	102%	100%	96%	88%	61%	33%	22%	23%	26%	28%	30%	59%	4%	138%
5	25%	25%	23%	23%	21%	35%	62%	79%	87%	90%	95%	98%	98%	98%	96%	91%	82%	64%	36%	21%	20%	22%	22%	24%	56%	6%	158%
6	18%	20%	21%	19%	18%	35%	63%	79%	86%	89%	90%	88%	87%	87%	84%	79%	72%	62%	38%	17%	12%	14%	15%	16%	50%	3%	132%
7	17%	18%	17%	17%	16%	26%	50%	65%	68%	69%	67%	67%	66%	66%	63%	60%	54%	45%	26%	11%	8%	10%	13%	16%	39%	1%	88%
8	16%	16%	16%	17%	15%	19%	43%	67%	71%	72%	73%	72%	70%	69%	66%	64%	58%	44%	21%	10%	10%	12%	14%	15%	40%	1%	113%
9	19%	20%	19%	19%	18%	18%	36%	68%	82%	83%	79%	79%	77%	76%	75%	72%	60%	34%	14%	11%	13%	15%	18%	19%	43%	1%	115%
10	32%	31%	29%	27%	26%	24%	30%	57%	78%	82%	84%	83%	83%	85%	85%	79%	51%	24%	18%	19%	23%	26%	28%	29%	47%	2%	138%
11	29%	29%	27%	26%	22%	21%	26%	43%	60%	68%	68%	68%	68%	68%	65%	51%	30%	19%	21%	23%	24%	27%	29%	29%	39%	4%	110%
12	27%	26%	27%	26%	24%	23%	22%	30%	43%	55%	58%	58%	57%	57%	53%	42%	26%	19%	21%	22%	23%	25%	26%	28%	34%	4%	87%
Average	25%	25%	24%	23%	22%	25%	38%	57%	70%	76%	77%	78%	77%	77%	76%	70%	57%	39%	24%	18%	19%	21%	22%	24%			

- The power penetration of intermittent resources will increase substantially between 2021 and 2030 as more solar is introduced in the system.
- Exceeding 60% penetration is potentially problematic for islanded systems, while exceeding 100% relies strongly on the tie-lines to neighboring utilities.

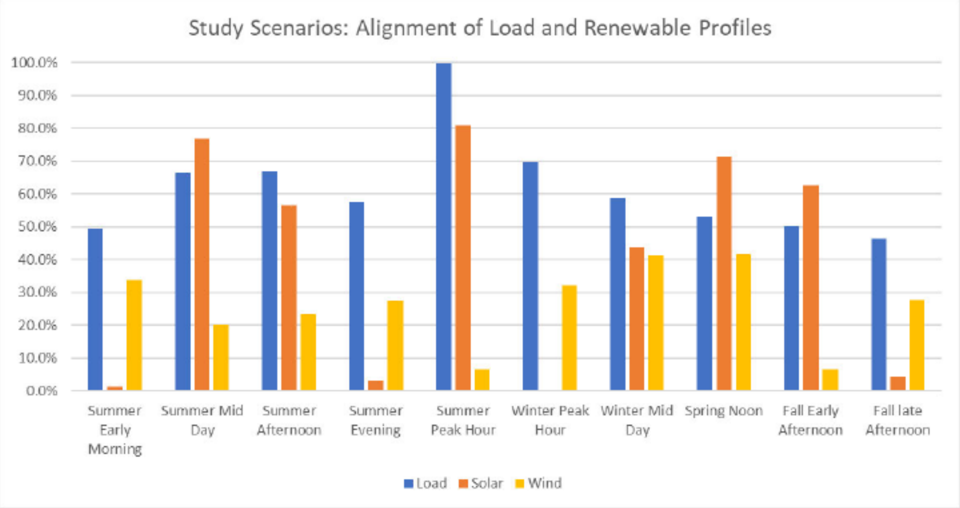
Reliability Assessment Study

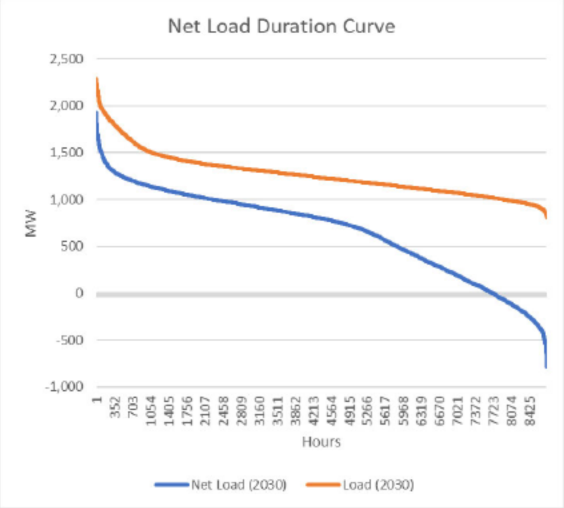
Content:

Series of filters to Assess System Reliability

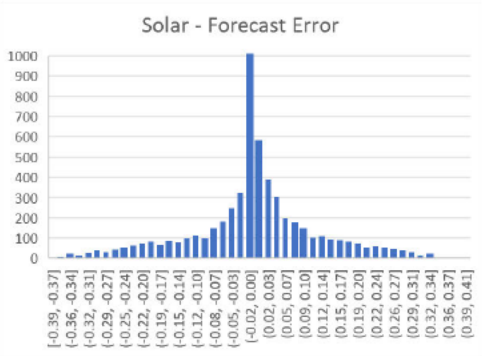
Resource Variability Analysis - Summary

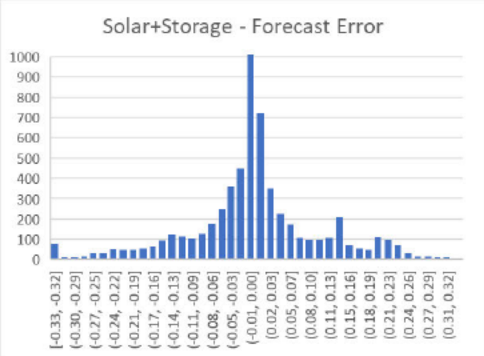
- The hourly profiles of Solar, Wind, and Solar plus Storage are characterized across two dimensions:
  - Forecast Error
  - Alignment with Load
- This characterization is utilized in subsequent evaluation of portfolios of these resources.

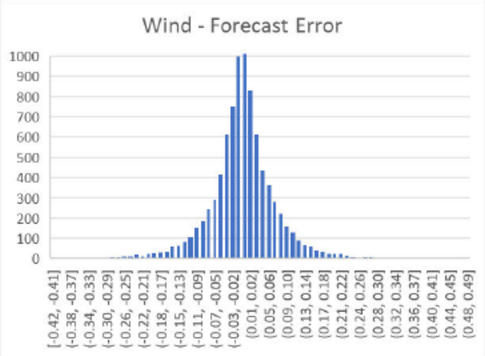




Forecast Error%	Solar	Wind	S+S
Standard Deviation	9.9%	7.5%	9.2%
min Error	-39%	-42%	-33%
max Error	39%	48%	33%
90% Percentile	19%	8%	12%

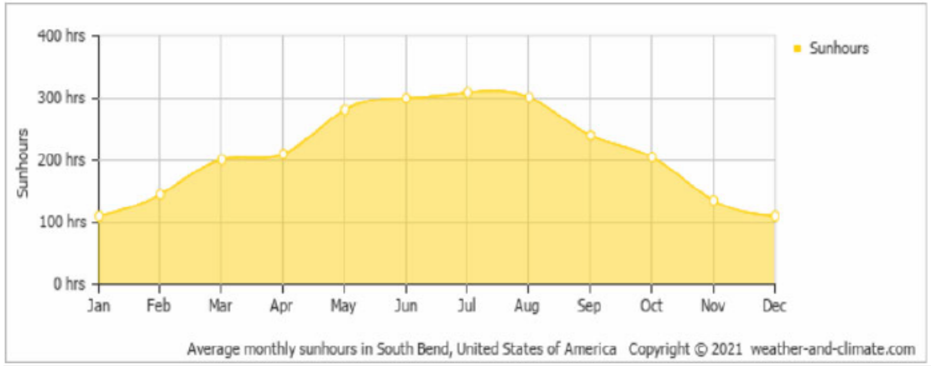






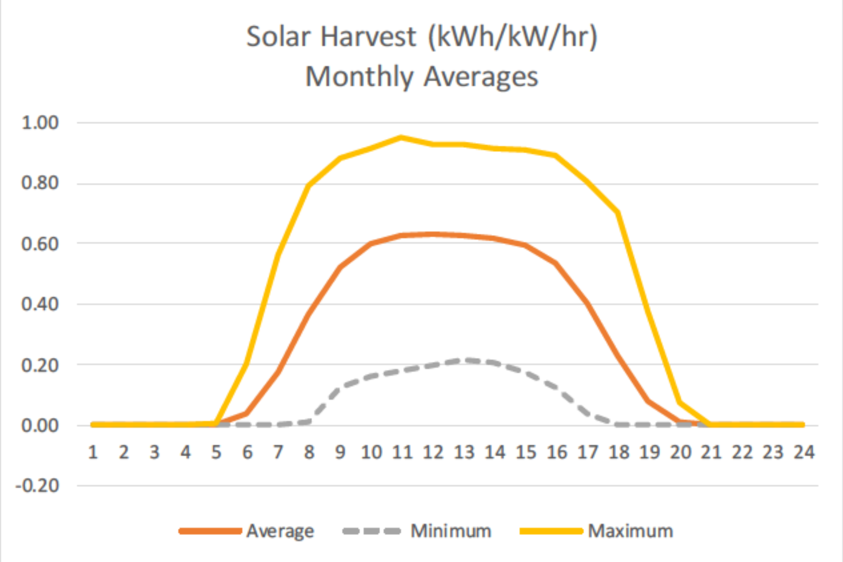
QUANTA TECHNOLOGY

Renewable Resource - Solar



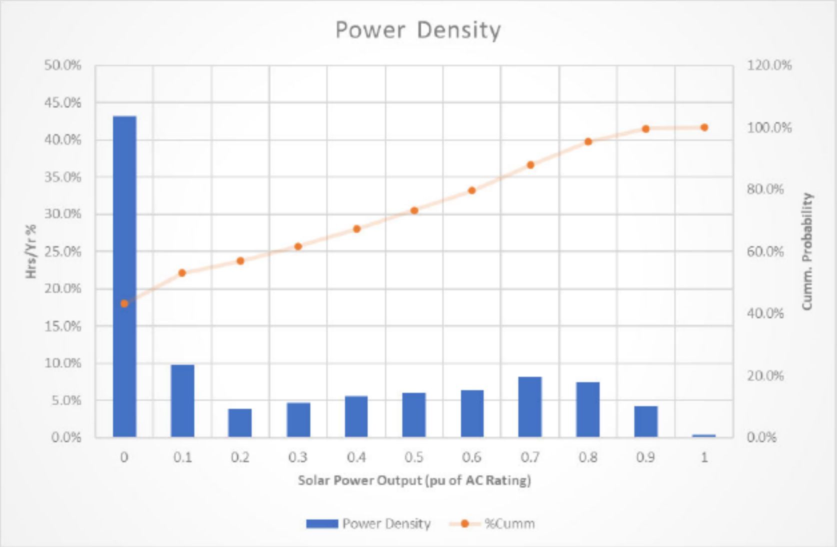
	Average Solar Irradiance (Kwh/kWac)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.03	0.11	0.15	0.11	0.04	0.00	0.00	0.00	0.00
7	0.00	0.00	0.06	0.25	0.38	0.43	0.39	0.29	0.18	0.06	0.04	0.01
8	0.03	0.12	0.31	0.51	0.57	0.62	0.61	0.56	0.50	0.32	0.18	0.08
9	0.21	0.34	0.52	0.62	0.66	0.72	0.72	0.69	0.68	0.53	0.35	0.21
10	0.35	0.47	0.59	0.67	0.70	0.77	0.78	0.75	0.73	0.60	0.44	0.33
11	0.39	0.51	0.63	0.70	0.74	0.80	0.80	0.78	0.74	0.61	0.46	0.35
12	0.39	0.51	0.65	0.72	0.75	0.80	0.82	0.80	0.74	0.60	0.45	0.35
13	0.40	0.51	0.65	0.71	0.74	0.80	0.82	0.80	0.73	0.58	0.45	0.35
14	0.40	0.50	0.63	0.69	0.72	0.79	0.82	0.78	0.72	0.58	0.44	0.35
15	0.39	0.50	0.60	0.66	0.69	0.77	0.79	0.75	0.71	0.57	0.40	0.30
16	0.34	0.46	0.55	0.61	0.63	0.70	0.74	0.70	0.67	0.51	0.29	0.21
17	0.14	0.30	0.44	0.53	0.54	0.62	0.65	0.62	0.54	0.27	0.11	0.07
18	0.02	0.08	0.19	0.32	0.40	0.49	0.51	0.42	0.24	0.06	0.00	0.00
19	0.00	0.00	0.03	0.09	0.15	0.24	0.24	0.14	0.04	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.02	0.05	0.05	0.01	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Month	Monthly Harvest (% of Max)
1	46%
2	49%
3	66%
4	80%
5	88%
6	99%
7	100%
8	92%
9	82%
10	60%
11	41%
12	29%



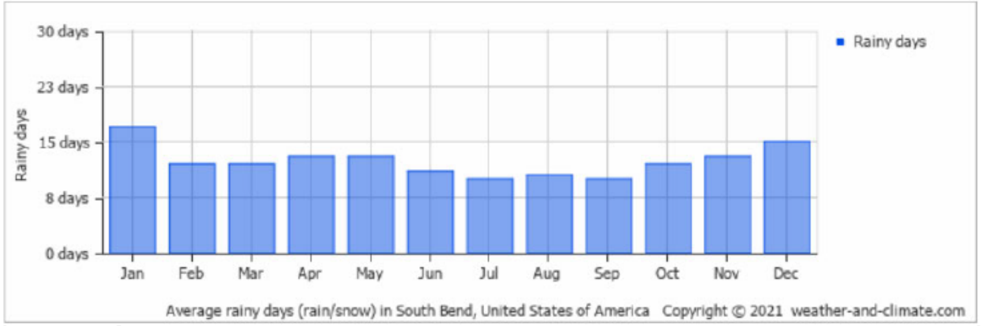
Annual Harvest kWh/kWac/Yr 2,204
Capacity Factor 25.16%

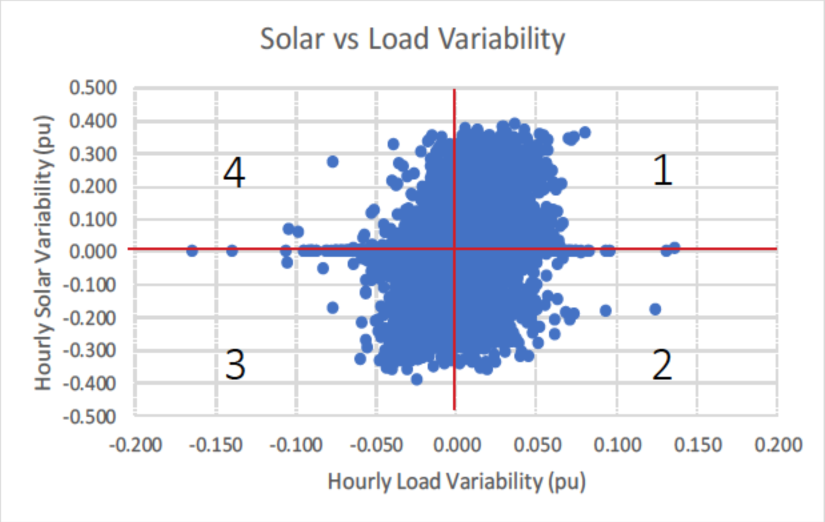
- Typical solar profile:
  - Jun-Aug highest
  - Dec lowest
- Annual solar harvest is higher by 10% than predicted by PV Watts for single-axis tracker systems.



Resource Variability - Solar

Location	Sunny Days Cloud Cover <30% during daylight hours	Partly Sunny Days Cloud Cover 40-70% during daylight hours	Total Days with Sun
Evansville	102	100	202
Fort Wayne	78	102	180
Indianapolis	88	99	187
South Bend	73	100	173
Average	**85.25**	**100.25**	**185.5**
%	23%	27%	51%





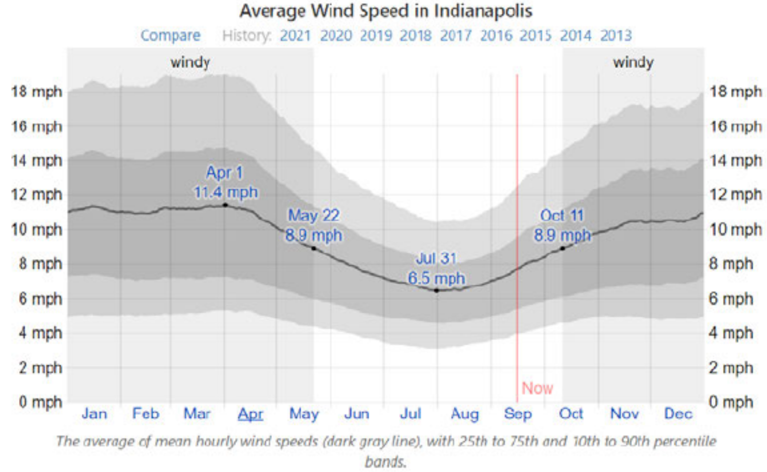
Quadrant	#hrs/Yr	%
0	3411	39%
1	1845	21%
2	1149	13%
3	1590	18%
4	765	9%
Total	8760	100%

Solar Power Variance (Standard Deviation pu)

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.01	0.03	0.03	0.03	0.01	0.00	0.00	0.00	0.00
7	0.00	0.00	0.02	0.04	0.08	0.07	0.08	0.05	0.03	0.02	0.02	0.00
8	0.01	0.03	0.07	0.07	0.10	0.09	0.10	0.08	0.07	0.07	0.04	0.02
9	0.06	0.07	0.10	0.09	0.11	0.09	0.11	0.08	0.09	0.09	0.08	0.05
10	0.08	0.09	0.11	0.08	0.10	0.08	0.10	0.08	0.08	0.09	0.09	0.10
11	0.07	0.09	0.10	0.08	0.10	0.08	0.09	0.07	0.07	0.08	0.07	0.09
12	0.06	0.08	0.08	0.09	0.09	0.07	0.08	0.05	0.06	0.07	0.07	0.08
13	0.06	0.08	0.09	0.09	0.08	0.08	0.07	0.05	0.05	0.08	0.08	0.08
14	0.07	0.09	0.08	0.10	0.08	0.08	0.07	0.06	0.07	0.09	0.09	0.09
15	0.09	0.10	0.09	0.10	0.08	0.08	0.09	0.07	0.07	0.09	0.09	0.09
16	0.09	0.09	0.10	0.11	0.08	0.09	0.09	0.07	0.08	0.09	0.07	0.06
17	0.04	0.06	0.10	0.10	0.08	0.09	0.10	0.07	0.08	0.05	0.03	0.02
18	0.01	0.02	0.05	0.07	0.07	0.08	0.10	0.05	0.04	0.01	0.00	0.00
19	0.00	0.00	0.01	0.03	0.04	0.05	0.06	0.02	0.01	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

- Only half the days in Northern Indiana have sun (sunny or partly cloudy), and the rain falls 10-15 days in a month.
- Solar output is unpredictable. Standard deviation of variability from forecast is expected to be around 4-11% (of name plate capacity).
- Solar is positively correlated with load (i.e., increases and decrease in unison) around 64% of the time and negatively correlated 36% of the time.

Renewable Resource - Wind



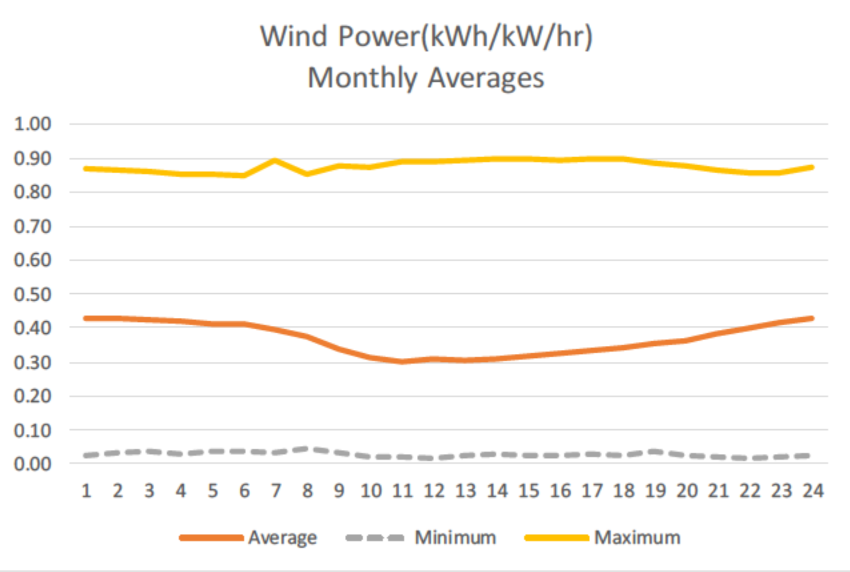
The average of mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands.

Average Wind Output (KWh/kWac)

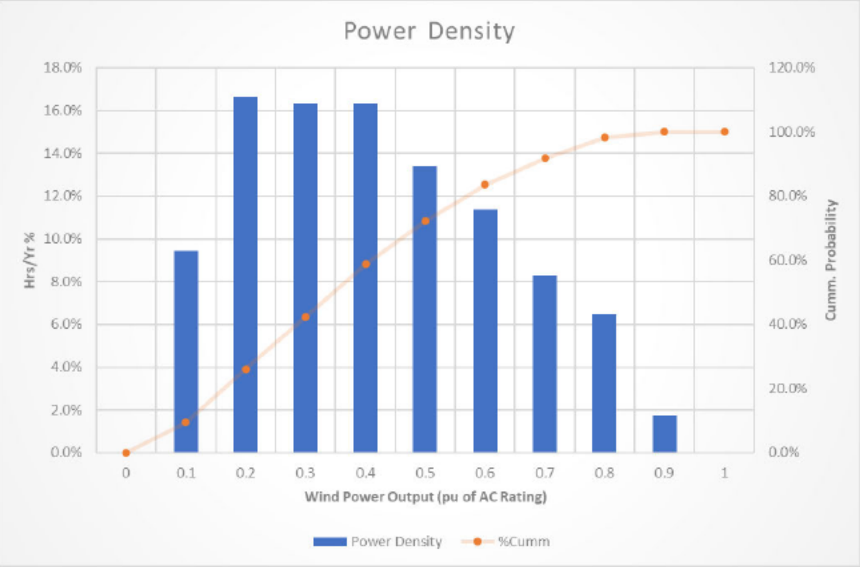
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.53	0.47	0.47	0.50	0.40	0.32	0.35	0.29	0.34	0.51	0.50	0.48
2	0.54	0.49	0.48	0.49	0.39	0.33	0.35	0.28	0.34	0.50	0.49	0.47
3	0.52	0.48	0.49	0.52	0.37	0.35	0.34	0.29	0.34	0.48	0.46	0.47
4	0.52	0.49	0.47	0.51	0.38	0.33	0.33	0.31	0.34	0.47	0.45	0.47
5	0.50	0.47	0.45	0.51	0.38	0.32	0.34	0.29	0.34	0.47	0.41	0.45
6	0.51	0.47	0.45	0.51	0.40	0.31	0.32	0.30	0.34	0.47	0.40	0.45
7	0.53	0.45	0.44	0.49	0.35	0.27	0.30	0.26	0.33	0.46	0.44	0.43
8	0.52	0.44	0.41	0.47	0.28	0.23	0.23	0.26	0.31	0.43	0.46	0.44
9	0.53	0.40	0.37	0.43	0.27	0.21	0.17	0.15	0.25	0.39	0.43	0.44
10	0.48	0.37	0.35	0.42	0.27	0.23	0.15	0.11	0.22	0.34	0.40	0.42
11	0.45	0.36	0.35	0.41	0.28	0.24	0.13	0.12	0.18	0.34	0.37	0.41
12	0.43	0.35	0.35	0.42	0.31	0.23	0.14	0.13	0.20	0.35	0.37	0.41
13	0.43	0.32	0.35	0.43	0.32	0.23	0.13	0.13	0.22	0.36	0.35	0.40
14	0.41	0.32	0.37	0.42	0.33	0.23	0.14	0.14	0.22	0.37	0.35	0.39
15	0.42	0.35	0.38	0.43	0.33	0.23	0.15	0.16	0.23	0.37	0.36	0.38
16	0.43	0.38	0.40	0.42	0.35	0.24	0.15	0.20	0.23	0.38	0.36	0.38
17	0.43	0.38	0.41	0.42	0.37	0.25	0.17	0.20	0.24	0.37	0.37	0.40
18	0.44	0.38	0.40	0.42	0.36	0.27	0.18	0.22	0.25	0.36	0.39	0.42
19	0.48	0.42	0.40	0.43	0.35	0.29	0.18	0.22	0.25	0.35	0.42	0.45
20	0.51	0.44	0.41	0.42	0.36	0.26	0.19	0.23	0.24	0.38	0.46	0.47
21	0.53	0.45	0.42	0.44	0.37	0.25	0.22	0.23	0.27	0.43	0.48	0.48
22	0.51	0.45	0.44	0.45	0.38	0.28	0.24	0.26	0.31	0.46	0.51	0.51
23	0.52	0.46	0.45	0.48	0.37	0.29	0.28	0.28	0.35	0.47	0.53	0.50
24	0.53	0.49	0.46	0.50	0.38	0.29	0.34	0.29	0.34	0.48	0.51	0.52

Month	Monthly Harvest (% of Max)
1	100%
2	80%
3	79%
4	86%
5	66%
6	51%
7	44%
8	42%
9	53%
10	79%
11	81%
12	84%

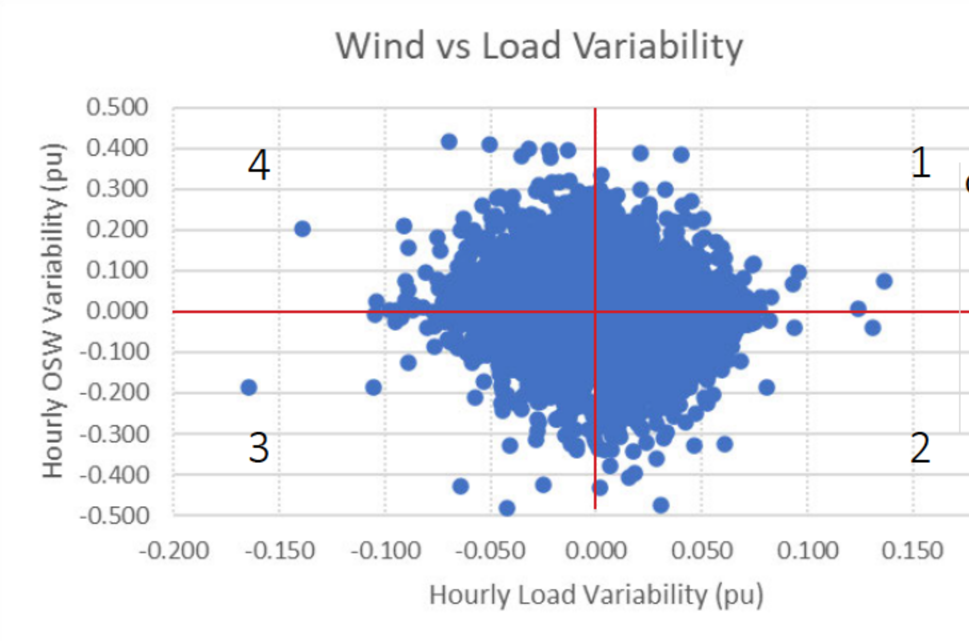
Annual Harvest kWh/kWac/Yr	3,223
Capacity Factor	36.80%



- Wind output is highest in Winter and lowest in Summer.
- Wind output is lowest from noon to 6PM.
- Wind output is above 50% of nameplate rating only 20% of the time.



Resource Variability - Wind



Quadrant	#hrs/Yr	%
0	1	0%
1	2078	24%
2	2316	26%
3	2008	23%
4	2357	27%
Total	8760	100%

- Wind output is unpredictable. Standard deviation of variability from forecast is expected to be around 7-25% (of name plate capacity). This is almost double the variability of solar PV.
- Wind is not correlated with load. It is just as likely to be positively correlated as negatively correlated.

	Wind Power Variance (Standard Deviation pu)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.18	0.21	0.24	0.23	0.18	0.14	0.16	0.20	0.14	0.20	0.20	0.16
2	0.18	0.20	0.22	0.21	0.18	0.14	0.18	0.18	0.14	0.19	0.19	0.17
3	0.16	0.20	0.24	0.20	0.15	0.16	0.17	0.18	0.14	0.20	0.16	0.18
4	0.14	0.21	0.23	0.18	0.16	0.17	0.15	0.18	0.14	0.20	0.17	0.17
5	0.15	0.22	0.23	0.17	0.16	0.16	0.15	0.19	0.15	0.19	0.17	0.18
6	0.16	0.22	0.23	0.17	0.17	0.15	0.14	0.18	0.15	0.20	0.17	0.17
7	0.17	0.22	0.22	0.18	0.16	0.14	0.14	0.17	0.13	0.20	0.17	0.17
8	0.17	0.21	0.23	0.19	0.16	0.13	0.12	0.14	0.14	0.20	0.17	0.17
9	0.19	0.19	0.23	0.21	0.17	0.14	0.12	0.08	0.13	0.20	0.17	0.18
10	0.17	0.20	0.22	0.23	0.18	0.15	0.12	0.07	0.16	0.22	0.19	0.19
11	0.18	0.20	0.22	0.23	0.18	0.14	0.08	0.09	0.17	0.25	0.20	0.20
12	0.19	0.21	0.23	0.23	0.19	0.14	0.10	0.10	0.17	0.24	0.19	0.20
13	0.19	0.20	0.22	0.23	0.18	0.13	0.09	0.12	0.16	0.23	0.18	0.20
14	0.20	0.18	0.23	0.22	0.18	0.12	0.10	0.13	0.15	0.24	0.16	0.19
15	0.20	0.19	0.23	0.20	0.19	0.13	0.11	0.13	0.15	0.24	0.17	0.19
16	0.20	0.20	0.24	0.19	0.19	0.13	0.11	0.17	0.14	0.25	0.18	0.18
17	0.19	0.20	0.24	0.20	0.19	0.15	0.11	0.17	0.13	0.25	0.19	0.18
18	0.19	0.21	0.24	0.19	0.18	0.16	0.12	0.17	0.12	0.23	0.17	0.17
19	0.18	0.22	0.24	0.21	0.18	0.15	0.11	0.17	0.12	0.21	0.19	0.16
20	0.19	0.22	0.23	0.21	0.17	0.13	0.10	0.18	0.16	0.21	0.20	0.16
21	0.19	0.22	0.22	0.20	0.17	0.13	0.12	0.18	0.17	0.20	0.22	0.17
22	0.19	0.23	0.20	0.21	0.16	0.15	0.12	0.20	0.17	0.19	0.22	0.17
23	0.19	0.23	0.21	0.22	0.17	0.14	0.14	0.21	0.16	0.19	0.21	0.18
24	0.18	0.22	0.22	0.22	0.18	0.14	0.17	0.20	0.16	0.20	0.21	0.16

Industry Research on Wind Variability

- Source: NREL

Time Interval	Statistical Metric	14 Turbines		61 Turbines		138 Turbines		250+ Turbines	
		(kW)	(%)	(kW)	(%)	(kW)	(%)	(kW)	(%)
1 (one) Second	Average	41	0.4	172	0.2	148	0.1	189	0.1
	Standard Deviation	56	0.5	203	0.3	203	0.2	257	0.1
1 (one) Minute	Average	130	1.2	612	0.8	494	0.5	730	0.3
	Standard Deviation	225	2.1	1,038	1.3	849	0.8	1,486	0.6
10 (ten) Minutes	Average	329	3.1	1,658	2.1	2,243	2.2	3,713	1.5
	Standard Deviation	548	5.2	2,750	3.5	3,810	3.7	6,418	2.7
1 (one) Hour	Average	736	7.0	3,732	4.7	6,582	6.4	12,755	5.3
	Standard Deviation	1,124	10.7	5,932	7.5	10,032	9.7	19,213	7.9

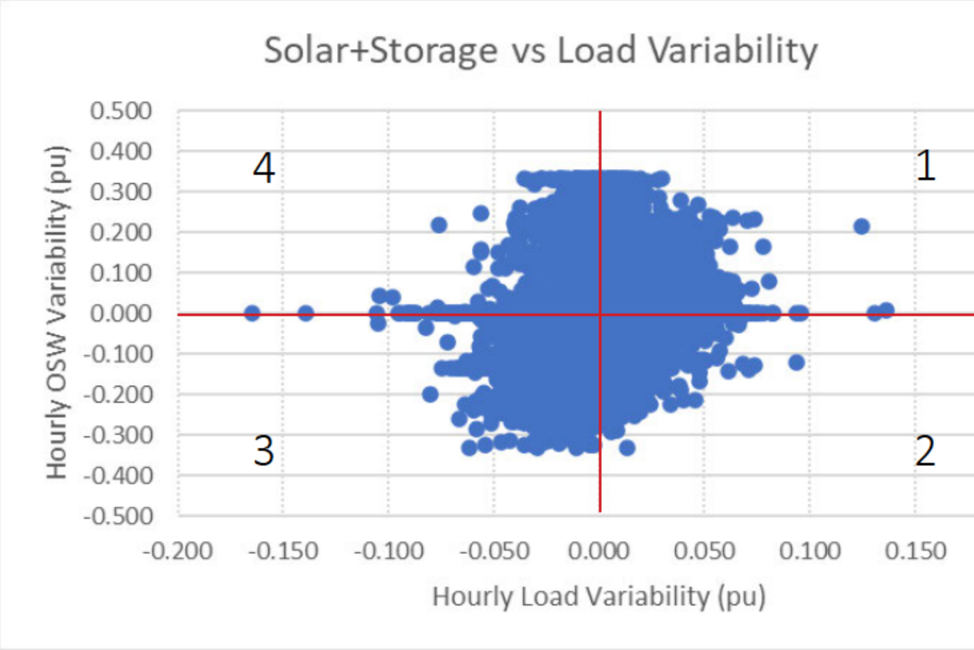
Renewable Resource – Solar plus Storage

- Solar plus Storage profile depends not only on the solar irradiance profile, but also on the size (MW and MWh) of the co-located storage system, and the control strategy of the storage system.
- In this analysis, the MW rating of storage is taken as 50% of the solar rating, and the capacity is 4 hours. The storage charge/discharge strategy is time-based and restricted to charging from the solar system (not the grid). The charge window is from 8AM to 4PM, and the discharge window is from 6PM to 10PM. The charging and discharging power ensure the state of charge stays within the limits of 0-100%. The round trip efficiency is 85%.
- Based on this charge/discharge strategy, the storage system accumulates 280 cycles per year (full depth) based on energy throughput.
- The capacity factor based on combined rating of solar and storage is calculated to be 16%.

Average Solar+Storage Output (KWh/kWac)

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.02	0.07	0.10	0.07	0.03	0.00	0.00	0.02	0.00
8	0.02	0.08	0.08	0.16	0.25	0.28	0.26	0.19	0.12	0.04	0.11	0.05
9	0.07	0.11	0.13	0.18	0.22	0.25	0.24	0.21	0.18	0.11	0.11	0.07
10	0.12	0.17	0.20	0.25	0.27	0.31	0.31	0.29	0.29	0.20	0.15	0.11
11	0.13	0.19	0.24	0.28	0.30	0.34	0.35	0.33	0.32	0.23	0.16	0.12
12	0.13	0.19	0.26	0.30	0.33	0.36	0.37	0.35	0.32	0.24	0.16	0.12
13	0.13	0.18	0.27	0.31	0.33	0.37	0.38	0.37	0.32	0.24	0.16	0.12
14	0.13	0.18	0.26	0.31	0.32	0.37	0.38	0.37	0.32	0.23	0.15	0.12
15	0.13	0.18	0.25	0.29	0.31	0.36	0.38	0.36	0.31	0.23	0.14	0.10
16	0.11	0.16	0.23	0.27	0.29	0.34	0.36	0.33	0.31	0.22	0.10	0.07
17	0.09	0.20	0.34	0.40	0.42	0.47	0.49	0.47	0.45	0.34	0.08	0.04
18	0.01	0.06	0.24	0.35	0.36	0.41	0.43	0.42	0.36	0.18	0.01	0.00
19	0.33	0.33	0.43	0.55	0.60	0.66	0.67	0.62	0.49	0.37	0.33	0.33
20	0.32	0.33	0.35	0.39	0.44	0.50	0.50	0.43	0.36	0.33	0.32	0.27
21	0.15	0.27	0.33	0.33	0.35	0.37	0.36	0.34	0.33	0.31	0.21	0.09
22	0.01	0.05	0.08	0.12	0.13	0.13	0.13	0.13	0.12	0.07	0.03	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Resource Variability – Solar plus Storage



Quadrant	#hrs/Yr	%
0	2786	32%
1	2001	23%
2	1072	12%
3	1779	20%
4	1122	13%
Total	8760	100%

Solar+Storage Power Variance (Standard Deviation pu)

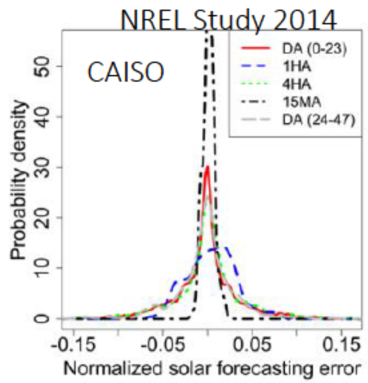
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
7	0.00	0.00	0.01	0.03	0.06	0.05	0.05	0.03	0.02	0.01	0.01	0.00
8	0.01	0.02	0.04	0.04	0.06	0.06	0.06	0.05	0.04	0.03	0.03	0.01
9	0.02	0.02	0.05	0.06	0.07	0.06	0.07	0.05	0.06	0.05	0.03	0.02
10	0.03	0.05	0.06	0.05	0.07	0.06	0.07	0.05	0.05	0.05	0.04	0.03
11	0.03	0.05	0.06	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.03	0.03
12	0.02	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.03
13	0.02	0.04	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.05	0.03	0.03
14	0.03	0.05	0.05	0.06	0.05	0.05	0.05	0.04	0.04	0.05	0.04	0.03
15	0.03	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.05	0.05	0.04	0.03
16	0.03	0.04	0.09	0.07	0.06	0.06	0.06	0.05	0.05	0.06	0.03	0.02
17	0.03	0.04	0.06	0.06	0.06	0.06	0.07	0.05	0.05	0.03	0.02	0.01
18	0.00	0.02	0.11	0.05	0.05	0.05	0.07	0.03	0.03	0.05	0.07	0.00
19	0.00	0.00	0.01	0.02	0.03	0.03	0.04	0.02	0.01	0.00	0.00	0.00
20	0.03	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.05	0.04	0.08
21	0.11	0.08	0.08	0.02	0.01	0.01	0.01	0.01	0.02	0.05	0.13	0.11
22	0.02	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

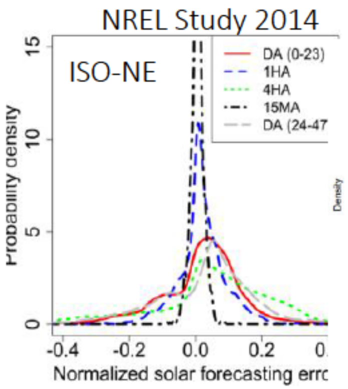
- Significantly lower variability and higher predictability of output than solar PV alone during the hours of storage operation while the State of charge is not depleted. The standard deviation of output is around 2-7% and compares favorably to solar's standard deviation of 7-11%.
- Correlation between Solar+Storage output and load is similar to solar PV's correlation. It is positively correlated with load (i.e., increases and decrease in unison) around 63% of the time and negatively correlated 37% of the time.

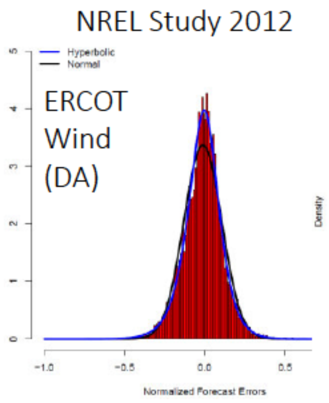
Forecast Errors

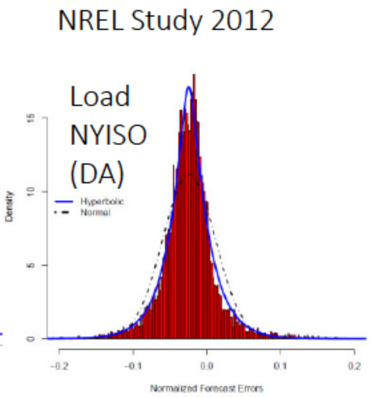
- **Using a persistent forecast method** (output in next period forecasted to be the same as current period):

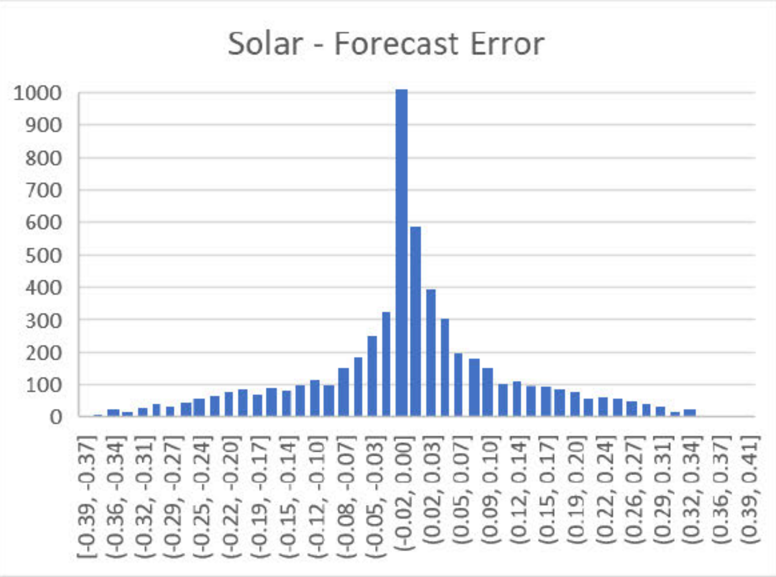
	Solar	Wind	S+S
Standard Deviation	9.9%	7.5%	9.2%
min Error	-39%	-42%	-33%
max Error	39%	48%	33%
90% Percentile	19%	8%	12%

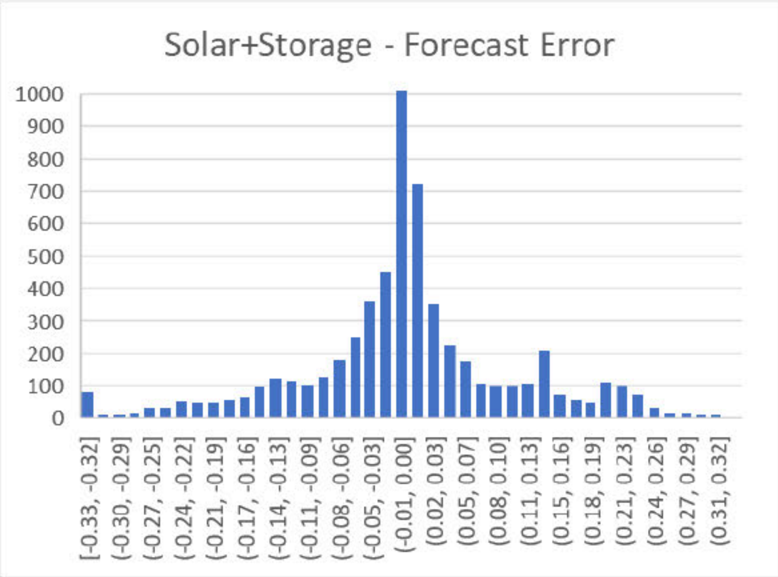


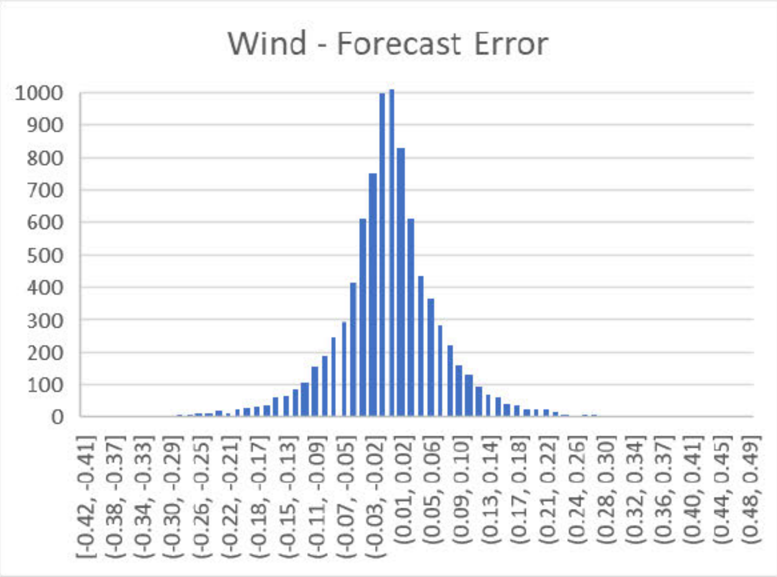




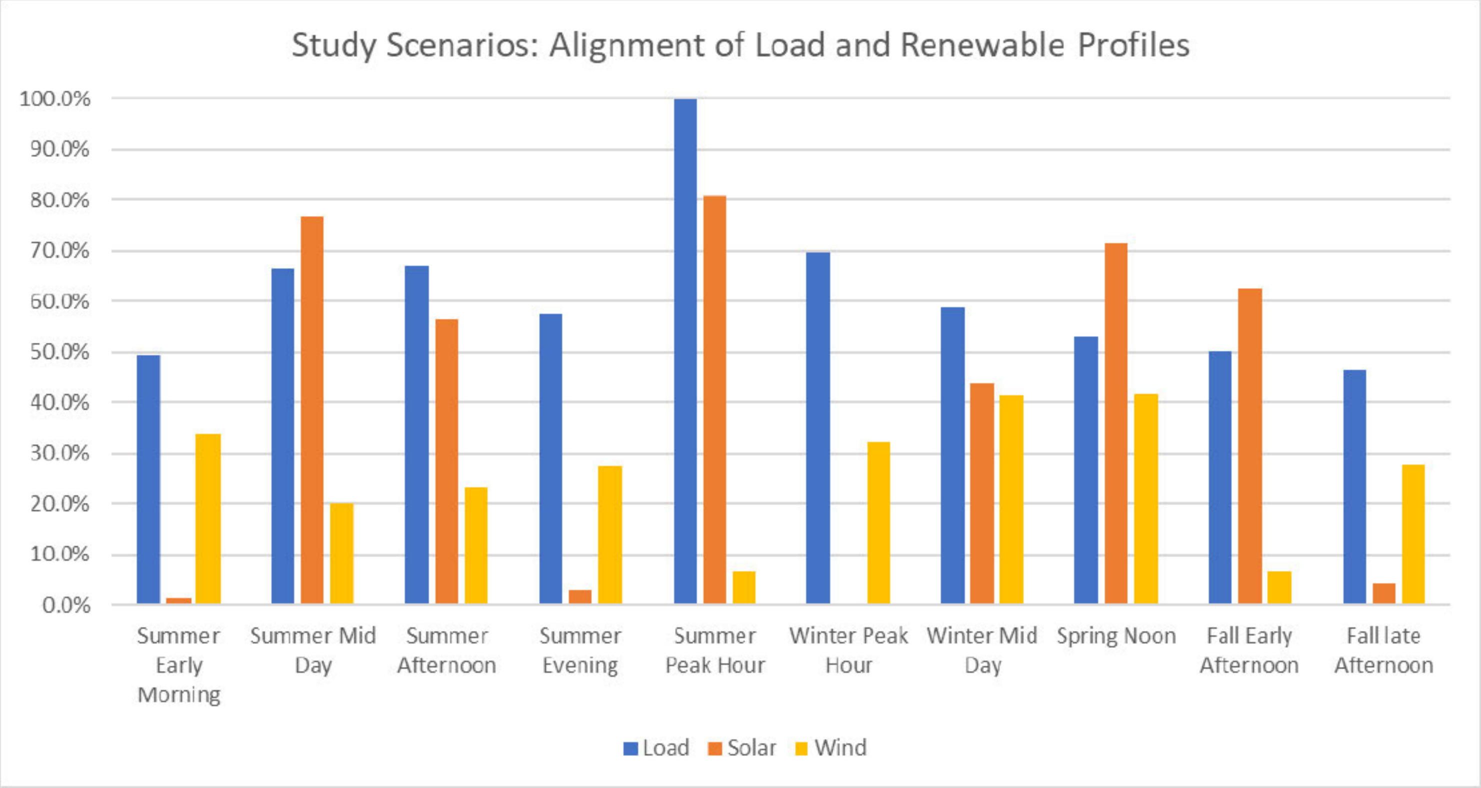








Alignment of Renewables and Load Profiles



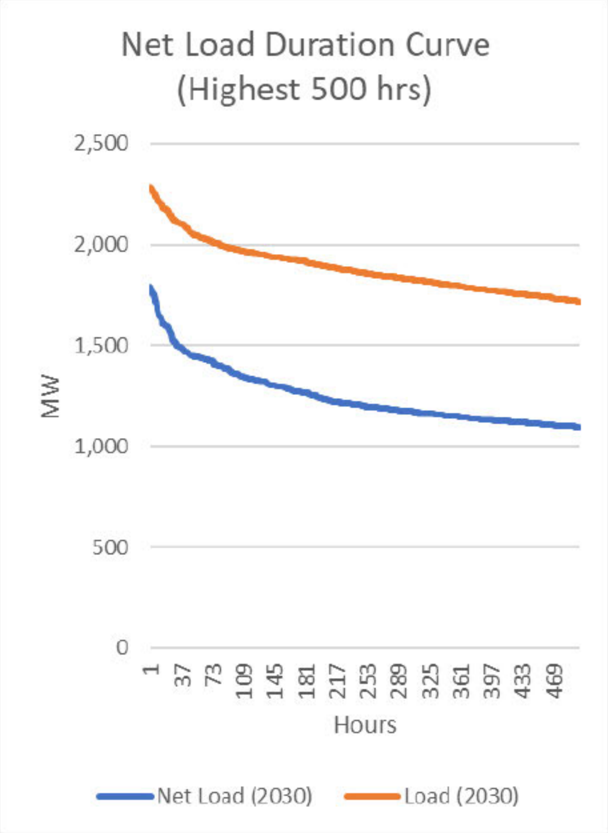
Name	From Month	To Month	From Day	To Day	From Hour	To Hour
Summer Early Morning	5	9	1	31	0	5
Summer Mid Day	5	9	1	31	9	13
Summer Afternoon	5	9	1	31	15	17
Summer Evening	5	9	1	31	18	23
Summer Peak Hour	7	7	10	10	15	15
Winter Peak Hour	1	1	30	30	18	18
Winter Mid Day	1	2	1	31	9	13
Spring Noon	4	4	1	31	11	12
Fall Early Afternoon	10	10	18	18	13	13
Fall late Afternoon	10	10	19	19	17	17

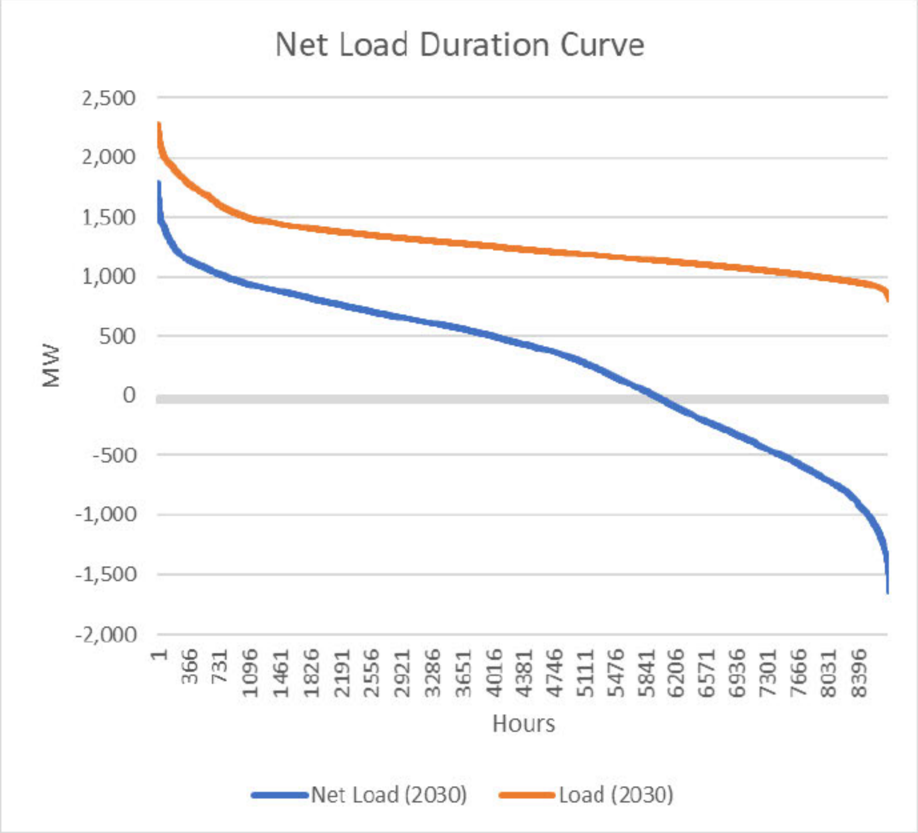
- The alignment of solar and wind profiles with Load Profiles creates periods of high renewable penetration and others with low penetration. Selecting study snap shots that exhibit pronounced interactions depends on the proper selection of these time periods.
- During Summer Peak hour, solar is high while wind is low. However, during Spring Noon hours, solar and wind are high. Periods when the solar profile exceeds the load profile are Summer Mid Day, Spring Noon, and Fall Early Afternoon.

Net Load (Y2030) and Capacity Benefit

- Net Load is calculated by subtracting the intermittent Solar, Wind, and Solar+Storage renewable resource outputs from the Load.
- An example is the Net Load after the addition of Portfolio F:
  - Portfolio E introduces 100 MW of additional intermittent renewable resources to bring the total in 2030 to 3,446MW consisting of 2,440MW of solar PV and 1,006MW of wind.
  - The peak of the Net Load is lower than the Peak of the Load by 491 MW. This provides a basis to grant the mix of renewables a capacity benefit ratio of 491/3446=14.2%.
  - The intermittent output will exceed the Load to drive the Net Load to become negative during 2,802 hours in the year, reaching as much as 1,636 MW negative.

Portfolio F (All Resources inside and outside service area)





Reliability Assessment Study

Content:

Series of filters to Assess System Reliability

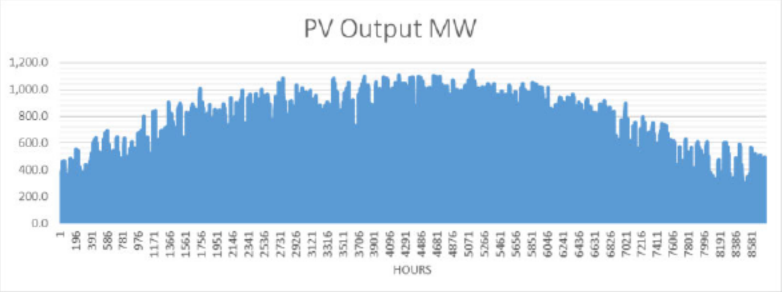
Energy Adequacy – Islanded Operation

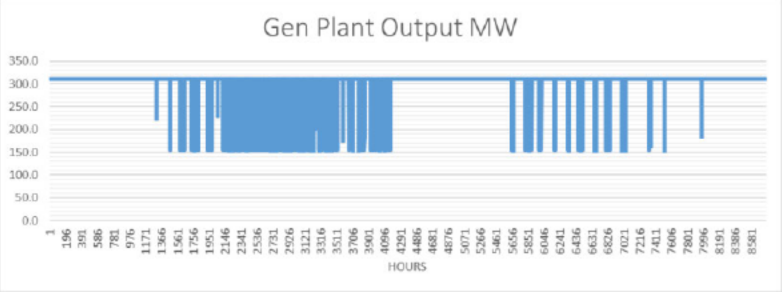
2030

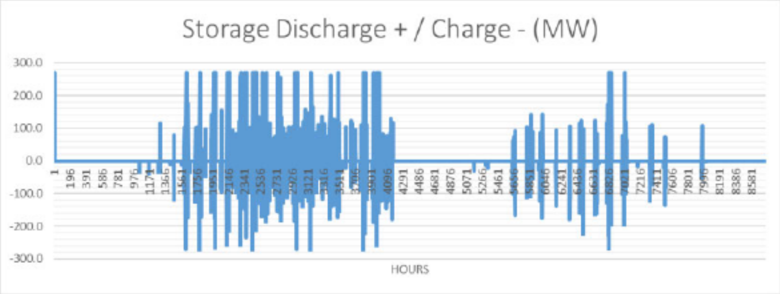
Portfolio	Solar PV MW	Wind MW	Energy Storage MW	Thermal Gen MW	Hyrdo	IBR %	Energy Not Served (GWh/Yr)	Energy Not Served 1-Yr (%)	ENS Worst 1-Week (%)	ENS Worst 1-hr (%)	Storage Avg Cycles/Day	Renewable Curtailment %
A	1,674	606	420	0	10	100%	6,031	54.4%	76.0%	99.0%	0.17	0.5%
B	1,224	606	135	0	10	99%	6,988	63.1%	79.5%	99.0%	0.02	0.1%
C	1,124	606	135	650	10	74%	2,031	18.3%	31.6%	63.2%	0.51	2.0%
D	1,824	606	420	0	10	100%	5,750	51.9%	74.8%	99.0%	0.27	1.4%
E	1,374	606	605	0	10	100%	6,658	60.1%	78.3%	99.0%	0.03	0.0%
F	1,224	606	270	300	10	87%	4,456	40.2%	55.7%	91.4%	0.12	0.3%
G	1,874	606	420	0	10	100%	5,664	51.1%	74.4%	99.0%	0.31	1.9%
H	1,374	806	705	0	10	100%	6,020	54.3%	73.2%	98.8%	0.05	0.0%
I	1,374	806	505	193	10	93%	4,431	40.0%	57.9%	88.1%	0.15	0.5%

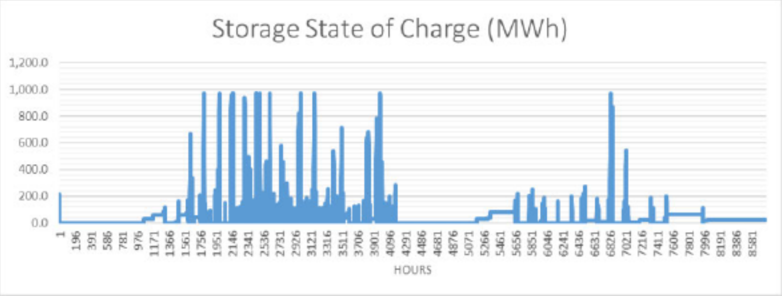
- The analysis simulates each portfolio in the year 2030 from an energy adequacy perspective when NIPSCO is operating in an islanded mode under emergency conditions and assesses its ability to meet the demand requirements across all 8760 hours of the year. The outcome of the simulations are the energy not served (GWh) if the system operates in islanded mode for 1 year, the worst energy not served if the islanded mode lasts for 1 week, and for 1 hour. Additional results are the average daily utilization of energy storage assets (cycles/day) and the level of renewable curtailment.
- The portfolios can be ranked as to their ability to serve the load as follows: C, I, F, G, D, H, A, E, B
- Notes: All the resources in each portfolio in addition to all other existing and planned resources are assumed to continue serving NIPSCO load; Energy storage is assumed to have 4 hours of capacity.

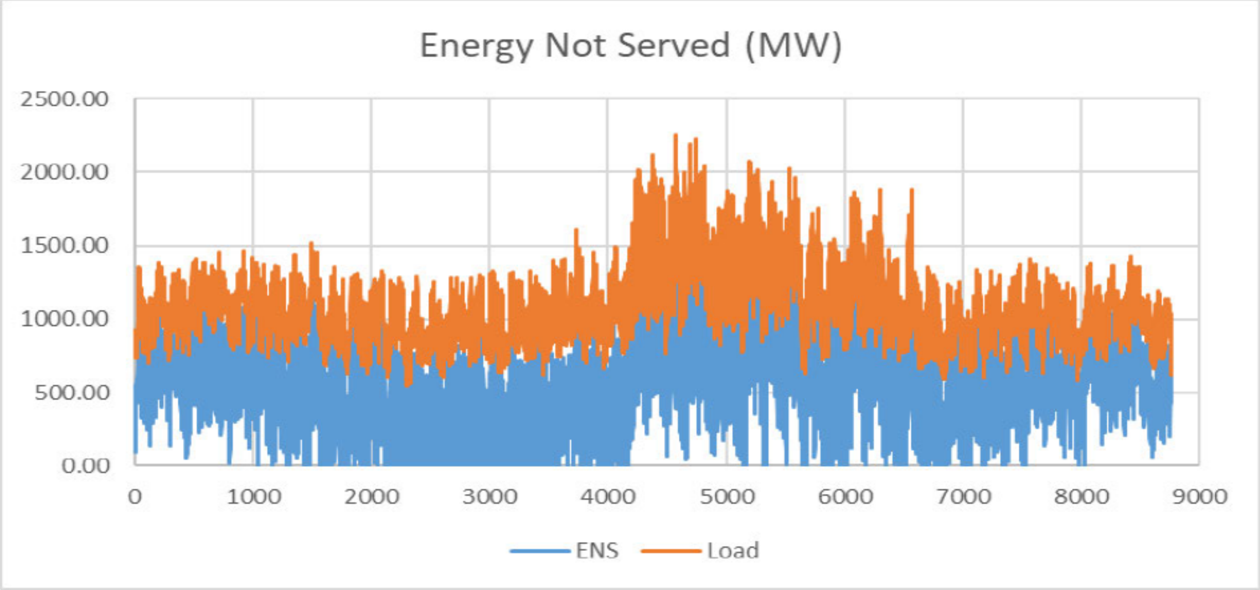
Representative Simulation Results – Portfolio F











- The graph shows the hourly load profile and the energy-not-served (ENS) at each hour of the year 2030.
- The simulation dispatched the peaker plant and the energy storage assets against the net native load after deducting solar and wind outputs. Solar curtailment was enforced during periods when the storage was fully charged, and the plant was at minimum output level.
- The peaker plant was assumed fully flexible (no ramp limits), but with a Pmin of 50% of its rating.
- The energy storage systems were assumed to have 4 hours of capacity, and round-trip-efficiency of 85%.

QUANTA TECHNOLOGY

Energy Adequacy – Emergency Operation

50/50 Forecast	A	B	C	D	E	F	G	H	I
Peak Load MW	2,284	2,284	2,284	2,284	2,284	2,284	2,284	2,284	2,284
Annual Load GWh	11,079	11,079	11,079	11,079	11,079	11,079	11,079	11,079	11,079
# Import Hrs	623	124	90	1,310	102	136	1,618	159	127
Import Hrs %	7%	1%	1%	15%	1%	2%	18%	2%	1%
# Potential Export Hrs	4,847	8,139	8,311	4,124	3,352	6,658	3,942	2,710	4,211
Export Hrs %	55%	93%	95%	47%	38%	76%	45%	31%	48%
Import GWh/Yr	95	17	11	232	14	18	317	24	17
Import Energy (% load GWh/yr)	0.9%	0.2%	0.1%	2.1%	0.1%	0.2%	2.9%	0.2%	0.2%
Max Import MW	715	467	410	865	440	475	918	511	465
Max Import (%Peak Laod)	31%	20%	18%	38%	19%	21%	40%	22%	20%

- The analysis simulates the need for energy imports, after accounting for all resources in the portfolio including energy storage and resources outside NIPSCO's service territory. The analysis uses the 50/50 load forecast.
- This analysis measures the level of energy deficit should MISO declare Emergency max gen event, whereby all resources aside from the ones owned or contracted by NIPSCO are unable to deliver additional power to the market.
- The portfolios can be ranked as to their ability to serve the load as follows: C/E, B/F/H/I, A, D, G
- Notes: All the resources in each portfolio (inside and outside of service territory) in addition to all other existing and planned resources are assumed to continue serving NIPSCO load; Energy storage is assumed to have 4 hours of capacity.

Energy Adequacy – Emergency Operation

50/50 Forecast	A	B	C	D	E	F	G	H	I
Peak Load MW	2,284	2,284	2,284	2,284	2,284	2,284	2,284	2,284	2,284
Annual Load GWh	11,079	11,079	11,079	11,079	11,079	11,079	11,079	11,079	11,079
# Import Hrs	623	124	90	1,310	102	136	1,618	159	127
Import Hrs %	7%	1%	1%	15%	1%	2%	18%	2%	1%
# Potential Export Hrs	4,847	8,139	8,311	4,124	3,352	6,658	3,942	2,710	4,211
Export Hrs %	55%	93%	95%	47%	38%	76%	45%	31%	48%
Import GWh/Yr	95	17	11	232	14	18	317	24	17
Import Energy (% load GWh/yr)	0.9%	0.2%	0.1%	2.1%	0.1%	0.2%	2.9%	0.2%	0.2%
Max Import MW	715	467	410	865	440	475	918	511	465
Max Import (%Peak Laod)	31%	20%	18%	38%	19%	21%	40%	22%	20%

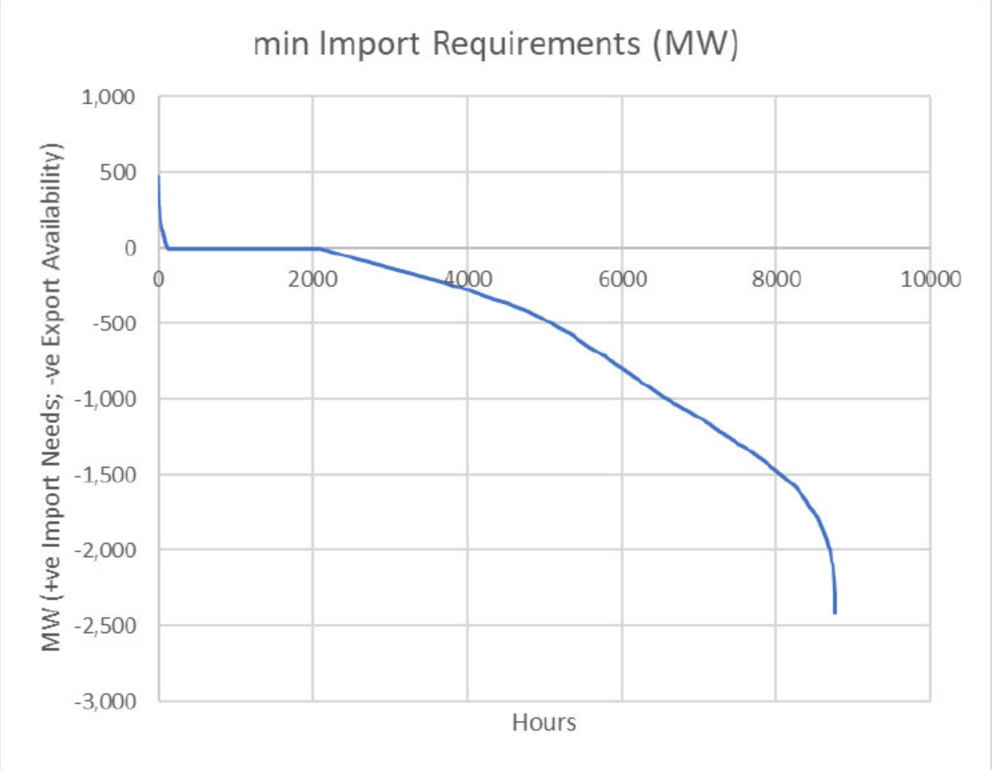
90/10 Forecast	A	B	C	D	E	F	G	H	I
Peak Load MW	2,444	2,444	2,444	2,444	2,444	2,444	2,444	2,444	2,444
Annual Load GWh	11,855	11,855	11,855	11,855	11,855	11,855	11,855	11,855	11,855
# Import Hrs	953	215	165	1,840	185	219	2,222	270	212
Import Hrs %	11%	2%	2%	21%	2%	3%	25%	3%	2%
# Potential Export Hrs	4,410	7,804	8,008	3,849	3,112	6,085	3,706	2,457	3,847
Export Hrs %	50%	89%	91%	44%	36%	69%	42%	28%	44%
Import GWh/Yr	171	36	26	397	30	38	522	47	36
Import Energy (% load GWh/yr)	1.4%	0.3%	0.2%	3.3%	0.3%	0.3%	4.4%	0.4%	0.3%
Max Import MW	853	605	548	1,003	578	613	1,056	649	603
Max Import (%Peak Laod)	35%	25%	22%	41%	24%	25%	43%	27%	25%

Risk Analysis	A	B	C	D	E	F	G	H	I
Increased Peak Load MW	160	160	160	160	160	160	160	160	160
Increased Annual Load GWh	776	776	776	776	776	776	776	776	776
Increased number of Import Hrs	330	91	75	530	83	83	604	111	85
Increase in Imported GWh/Yr	75	19	15	165	17	20	205	23	19
Increase in Max Import MW	138	138	138	138	138	138	138	138	138
% of Increased Load relying on Imports	9.7%	2.5%	1.9%	21.3%	2.2%	2.6%	26.4%	3.0%	2.4%

- Should the load during market emergency max gen event grow to 90/10 forecast (i.e., ≈7%), this analysis examines the ability of the portfolio to meet the energy requirements of the increased load.
- The analysis shows that Portfolio C can meet, on average, all the increase in load demand except 1.9%. This means it will be able to serve 98.1% of the increase in load.
- The portfolios can be ranked on their ability to serve the increase in load without relying on market purchases. The ranking from best to worst is:
  - C, E, I, B, F, H, A, D, G

Energy Adequacy – Emergency Operation

- Example: Portfolio F (using 50/50 Load Forecast)



# Import Hrs	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	2	0	0
7	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	15	17	10	6	2
8	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	17	17	6	2	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	7	3	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

- The analysis shows that Portfolio F is energy long and relies on energy purchases only 136 hours in a year (i.e., 2% of time) to meet its energy needs with a maximum purchase of 475MW, while it has excess energy to potentially sell 6,658 hours in a year (i.e., 76% of time).

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Series of filters to Assess System Reliability

Dispatchability

Portfolio	Additional Installed Capacity (MWs)			
	Total	Dispatchable	Non-Dispatchable	%Dispatchable
A	1,048	488	560	47%
B	906	646	260	71%
C	713	703	10	99%
D	1,048	338	710	32%
E	933	673	260	72%
F	748	638	110	85%
G	1,045	285	760	27%
H	1,030	570	460	55%
I	1,076	616	460	57%

- Portfolios ranked by highest % of dispatchable resources: C, F, E, B, I, H, A, D, G

Increase in Regulation Requirements

Portfolio	Increase in Freq Regulation Requirements (MW)
A	54
B	37
C	34
D	58
E	41
F	37
G	59
H	46
I	46

- The short-term intermittency of solar and wind resources increases the need for frequency regulation. This analysis quantifies the increased level of regulation services.

Power Ramping Capability

Y 2030

Portfolio	1-min Ramp Capability (MW)	10-min Ramp Capability (MW)
A	331	574
B	196	439
C	261	764
D	331	574
E	666	909
F	382	784
G	326	548
H	761	983
I	599	944

- The ramping capability of the system is measured at 1-min and 10-mins. The higher the ramping capability the better flexibility the system will have to respond to sudden disturbance.

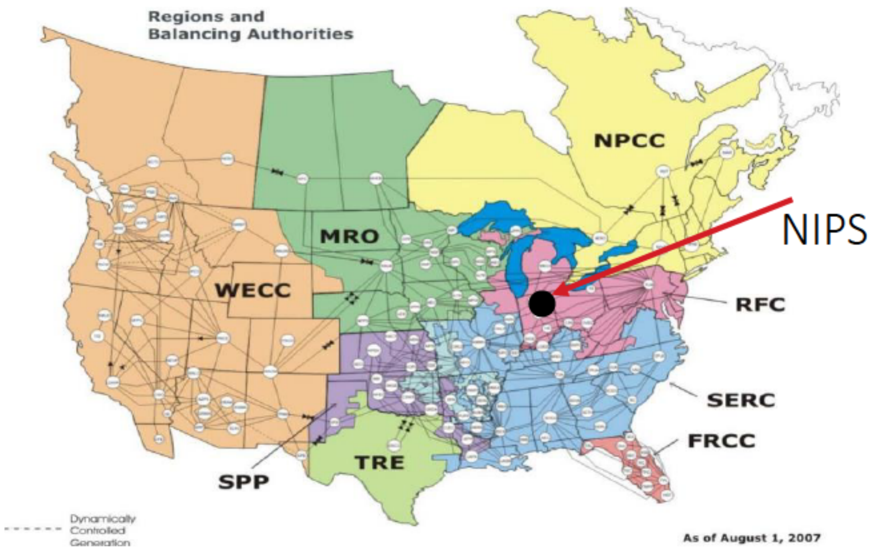
Reliability Assessment Study

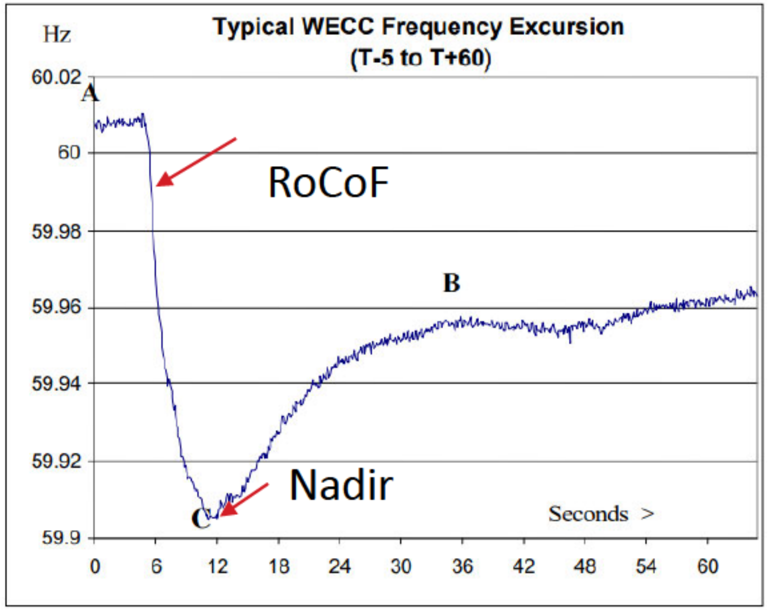
Content:

Series of filters to Assess System Reliability

Frequency Control - Overview

- NIPSCO operates a balancing control area, within the MISO balancing control area within the Eastern Interconnection.
- Dispatchers at each Balancing Authority fulfill their NERC obligations by monitoring ACE and keeping the value within limits that are generally proportional to Balancing Authority size.
- Generators contribute to the frequency response through Governors while loads contribute through their natural sensitivity to frequency. Frequency Response is measured as change in MW per 0.1Hz change in frequency. Governor's droop of 5% translates to a response of 3.3% while load response is typically 1-2%. Frequency Response is particularly important during disturbances and islanding situations. Per BAL-003, each balancing area should carry a frequency bias, whose monthly average is no less than 1% of peak load.
- Following the loss of a large generator, frequency drops initially at a rate (RoCoF) that depends on the level of inertia in the system. After few seconds, it will stabilize at a lower value (Nadir) due to the primary frequency response of generators and loads. Afterwards, AGC systems will inject regulation reserves that raise the frequency to within a settling range within a minute. Tertiary reserves are called upon if required to help.



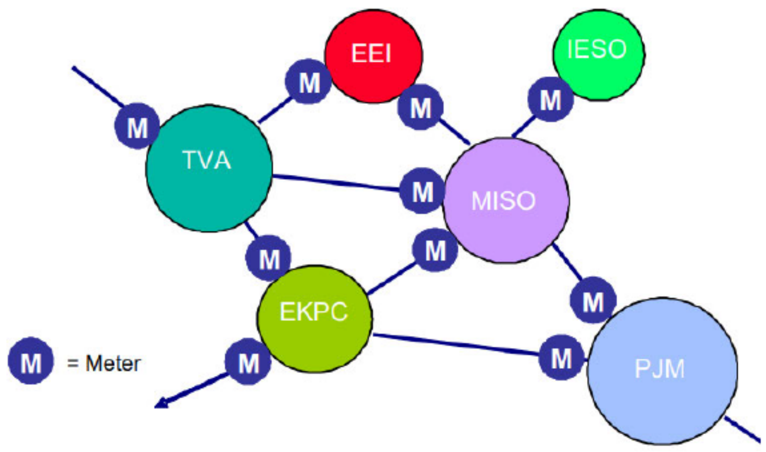


Control	Ancillary Service/IOS	Timeframe	NERC Standard
Primary Control	Frequency Response	10-60 Seconds	FRS-CPS1
Secondary Control	Regulation	1-10 Minutes	CPS1– CPS2 – DCS - BAAL
Tertiary Control	Imbalance/Reserves	10 Minutes - Hours	BAAL - DCS
Time Control	Time Error Correction	Hours	TEC

QUANTA TECHNOLOGY

Modeling Overview

- The NIPSCO system is connected to neighboring utilities through 69-765kV lines with a total line ratings of 28GW. The simultaneous import capability is estimated at 2,650MW while the export capability is estimated at 2,350MW.



- Most of the conventional generation capacity within NIPSCO system is planned for retirement and thus the system inertia is expected to decline.

Portfolio	2021		2025		2030	
	Summer Rating MW	Inertia MVA-s	Summer Rating MW	Inertia MVA-s	Summer Rating MW	Inertia MVA-s
A	1,830	6,845	1,120	5,002	598	3,218
B	1,830	6,845	1,120	5,002	598	3,218
C	1,830	6,845	1,170	5,272	1,248	6,729
D	1,830	6,845	1,120	5,002	598	3,218
E	1,830	6,845	1,120	5,002	598	3,218
F	1,830	6,845	1,120	5,002	898	5,116
G	1,830	6,845	1,120	5,002	545	2,931
H	1,830	6,845	1,120	5,002	545	2,931
I	1,830	6,845	1,313	6,198	791	4,397

Sugar Creek combined cycle plant is included in table, despite its location outside of NIPSCO's service area

Sum of Tie Line Ratings	RTO	69	138	345	765	Total
Ameren Illinois	MISO		245			245
American Electric Power	PJM	94	927	12,819	2,669	16,509
Commonwealth Edison	PJM		766	7,967		8,733
Duke Energy Indiana	MISO	44	430	2,106		2,580
Michigan Electrical	MISO		215			215
Total MVA		**138**	**2,583**	**22,892**	**2,669**	**28,282**

- The NIPSCO system will be assessed during normal operation when it is connected to the MISO system and under abnormal operation when it is isolated.

Frequency Response and Simplified Model

- Inertial Response
  - $$\frac{2H}{f_0}\frac{df}{dt} = \Delta P$$
  - ΔP = Loss of power resources due to contingency event

    + Variability of intermittent resources solar+wind resources at 1s

    - Virtual inertial contribution from online solar+wind resources

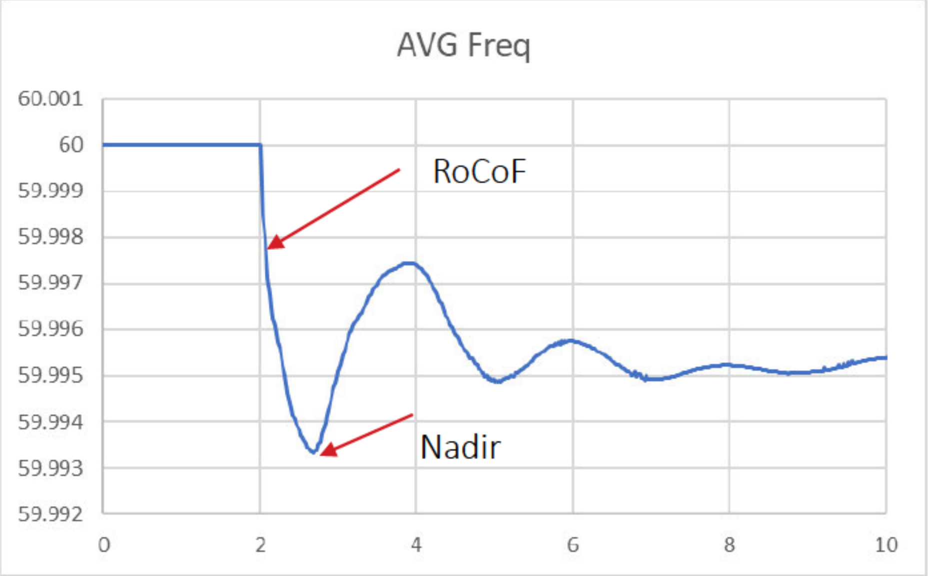
    - Virtual inertial contribution from battery energy storage

    - Inertial response contribution from outside areas over tie-lines

  - Inertia to limit RoCoF: H= ΔP/(2 x RoCoF Limit) f_0
  - Inertia to avoid triggering UFLS before the responsive reserves load: H=ΔP/(2 x UFLS speed) f_0;

    where UFLS speed = (pickup frequency – trip frequency)/delay

- Primary Freq Response
  - Δf(pu)= - (R .ΔP)/(D.R+1)
  - Where:
    - R is governor droop,
    - D is load damping,
    - ΔP is system disturbance, and all are in per unit using the same MW base value, such as system load level



Inertial Response (RoCoF)

Event	Loss of 420MW Gen									
Renewable Variability	Yes					No				
NIPSCO	Islanded					Connected				
Scenario	1	2	3	4	**5**	6	7	**8**	**9**	10

Scenario 5 → Summer Peak Hour
7/21 3PM
Load 100%; PV 81%; Wind 7%

Scenario 8 → Spring Noon
April 11-1PM
Load 53%; PV 63%%;Wind 42%

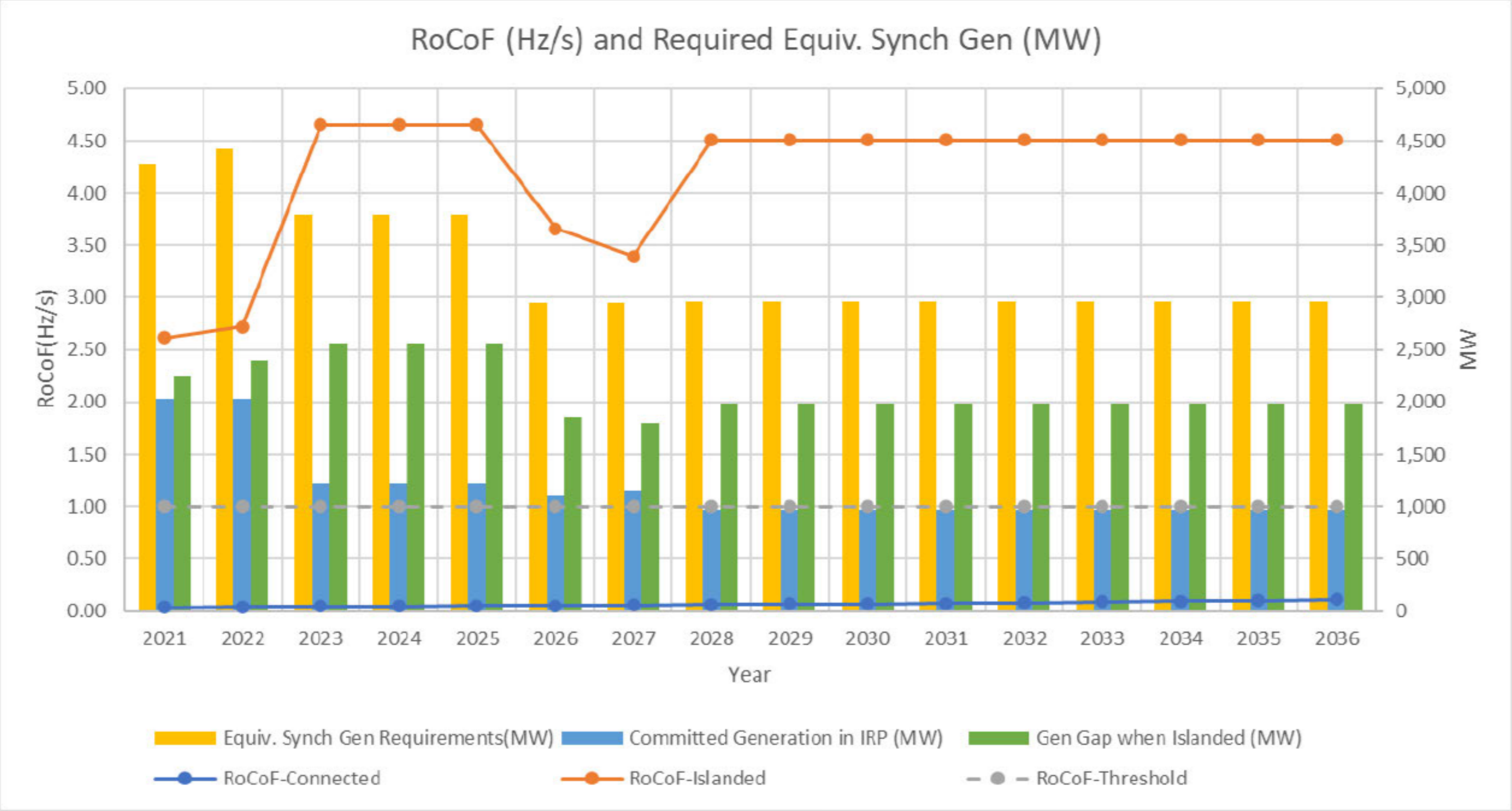
Scenario 9 → Fall Early Afternoon
10/18 1PM
Load 50%; PV 63%%; Wind 7%

Assumptions:

- No storage systems in the IRP are fitted with grid-forming inverters capable of inertial response.
- Wind can provide inertial response level of 11% of their nameplate rating.
- IBR adoption in the rest of MISO starts at 20% in 2021 and increases by 2.5% each year reaching 42.5% in 2030.
- Tie-line import capability limit connecting NIPS area of 2650 MW.
- Solar and OSW variability (1-second) of 5% of nameplate rating.

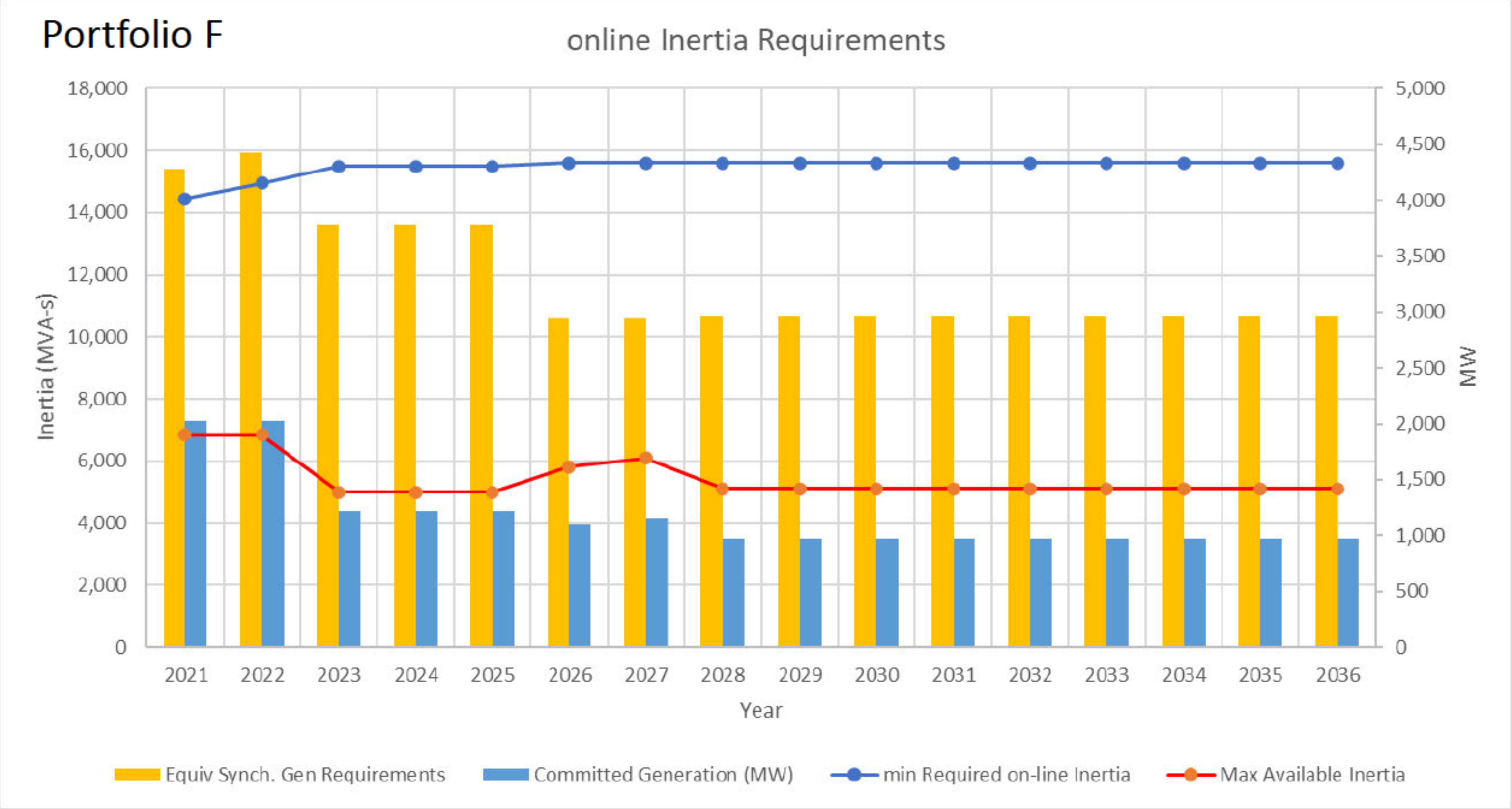
Inertial Response

- Using Portfolio F, the system inertial response was simulated during normal conditions when NIPSCO is connected to MISO and also during emergency conditions when it is islanded. The simulation is conducted assuming all available synchronous generation is committed.



- During normal operations when NIPSCO is connected to MISO system, RoCoF starts in 2021 at a small value of 0.04Hz/s and increases to 0.07Hz/s by 2030 and 0.17Hz/s by 2040. This increase is due to retirements of synchronous generation within NIPSCO system and also within MISO. However, it remains acceptable below 1.0Hz/s.
- When Islanded, RoCoF exceeds the acceptable threshold starting at 2.6Hz/s in 2021 and reaching 4.5Hz/s by 2028.
- When the Gas Peaker is added in 2026 and the storage in 2027, RoCoF drops, and then increases in 2028 when Michigan City 12 is retired.

Inertial Response



- An equivalent inertia of 15,592MVA-s is required to be on-line to maintain RoCoF within 1Hz/s. This can be accomplished by either committing additional synchronous generation or synchronous condensers equipped with fly wheels reaching 1,992 MW or equipping energy storage with grid forming inverters capable of delivering a combined inertial response of 349MW.

Inertial Response –Portfolio Ranking

								Normal System (Connected)			Islanded System				
Portfolio	On-Line Gen MVA (Y2021)	On-Line Gen MVA (Y2030)	On-Line Inertia MVA-s (Y2021)	On-Line Inertia MVA-s (Y2030)	Energy Storage MW (Y2030)	Fast Frequency Response (MW)	RoCoF Limit Hz/s	RoCoF Normal (Y2021)	RoCoF Normal (Y2030)	Gap Inertia (MVA-s)	RoCoF Islanded (Y2021)	RoCoF Islanded (Y2030)	Gap Inertia (MVA-s)	Required Mitigation BESS GFM[1] (MW)	Additional Required BESS GFM (MW)
A	2,236	757	6,845	3,218	270	377	1.00	0.04	0.08	0	2.61	12.74	15,960	425	155
B	2,236	757	6,845	3,218	135	242	1.00	0.04	0.07	0	2.61	12.40	15,592	412	277
C	2,236	1,573	6,845	6,729	135	359	1.00	0.04	0.07	0	2.61	2.90	15,485	292	157
D	2,236	757	6,845	3,218	270	377	1.00	0.04	0.08	0	2.61	12.89	16,121	430	160
E	2,236	757	6,845	3,218	605	712	1.00	0.04	0.07	0	2.61	12.55	15,753	418	0
F	2,236	1,169	6,845	5,116	270	441	1.00	0.04	0.07	0	2.61	4.51	15,592	349	79
G	2,236	690	6,845	2,931	270	368	1.00	0.04	0.08	0	2.61	17.57	16,174	441	171
H	2,236	690	6,845	2,931	705	803	1.00	0.04	0.07	0	2.61	16.85	15,603	422	0
I	2,236	1,013	6,845	4,397	505	652	1.00	0.04	0.07	0	2.61	5.95	15,603	374	0

[1]GFM : Battery Energy Storage equipped with Grid Forming Inverters

- The portfolios can be ranked based on the available fast frequency response capability within NIPSCO service territory: H, E, I, F, D, A, G, C, B
- All portfolios do not violate the inertial response threshold during normal interconnected operations
- During islanded operations:
    - Portfolios E, H, and I can meet the inertial threshold if 69%, 60%, and 74% of their storage is equipped with grid forming (GFM) inverters with inertial response functionality.
    - Other portfolios require additional storage in addition to equipping all their planned storage with GFIs.
- Ranking of Portfolios: I, E, H, F, A, C, D, G, B

Primary Frequency Response

Islanded System

Portfolio	Installed Generation MW (Y2021)	Installed Generation MW (Y2030)	Energy Storage MW (Y2030)	On-Line Reserves MW (Y2021)	On-Line Reserves MW Y2030)	Primary Freq Response (MW)	Freq Nadir Threshold (Hz)	Freq Nadir Hz (Y2021)	Freq Nadir Hz (Y2030)	Required Gen Resources (MW)	Requied Storage Resources (MW)	Load Drop (MW)
A	1,830	598	270	-428	16	225	0.50	16.87	0.88	1,116	259	673
B	1,830	598	135	-428	-445	113	0.50	16.87	1.70	1,756	387	999
C	1,830	1,248	135	-428	123	113	0.50	16.87	1.64	1,070	380	432
D	1,830	598	270	-428	140	225	0.50	16.87	0.88	1,122	260	549
E	1,830	598	605	-428	149	504	0.50	16.87	0.41	0	0	875
F	1,830	898	270	-428	-10	225	0.50	16.87	0.88	766	249	699
G	1,830	545	270	-428	128	225	0.50	16.87	0.88	1,180	261	561
H	1,830	545	705	-428	228	588	0.50	16.87	0.35	0	0	897
I	1,830	791	505	-428	274	421	0.50	16.87	0.48	16	19	651

On-Line Reserves measured at peak load inside NIPSCO

Online Reserves include generation and energy storage resources in excess of net load inside NIPSCO area

- The portfolios were simulated to assess the level of frequency drop in response to the sudden loss of 420MW of generation. The simulations were conducted when the system was in normal interconnected modes and did not find any reliability issues with any portfolio. However, when the system was simulated under emergency operation in islanded mode, several portfolios experienced frequency violation of the nadir dropping by more than 0.5Hz potentially triggering under frequency load shedding schemes.
- The analysis continued to quantify the level of additional fast response requirements from storage systems to mitigate the reliability violations.
- Note: The analysis assumed a droop of 5% for conventional assets, and 1% for storage assets, all limited by the resource ramp rates.

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Series of filters to Assess System Reliability

Dynamic Reactive Power Capability and Distance to Load

Y 2030

Portfolio	VAR Capability (MVAr)
A	1,118
B	797
C	1,037
D	1,183
E	1,067
F	987
G	1,205
H	1,198
I	1,195

Resources inside NIPSCO's service Territory including two synchronous condensers

- A large part of NIPSCO's baseload and industrial clients are located around the Lake.
- NIPSCO provides the dynamic reactive power requirements of these customers.
- The resources within NIPSCO footprint can generate dynamic reactive power. However, given the localized nature of reactive power, the closer "electrically" the generator VARs to the load centers, the more valuable they are to the system.
- The available dynamic VArs that can be produced are calculated assuming all resources have the capability to operate +/- 0.9 power factor.
- The electrical distance of each resource to each load point is calculated using the Zbus matrix in the form of electrical impedance. The impedance from each resource to the "Center of Load" is also calculated.
- Each portfolio will be evaluated based on its ability to deliver its dynamic VARs to the load centers as follows:
  - The dynamic VARs that can be delivered to the center of load after accounting for line impedance losses is utilized to rank portfolios.
  - Since reactive power does not travel well, resources outside of NIPSCO's service territory are excluded from this analysis.

Dynamic Reactive Power and Distance to Load

	A	B	C	D	E	F	G	H	I
Qload (MVArs)	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208
Qload (Load pu)	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335
Synch Condensers (MVAr)	0	0	0	0	0	0	0	0	0
Pgen (MW) - Total	2,564	1,829	2,379	2,714	2,448	2,264	2,764	2,748	2,742
Qgen (MVAr) - Total	1,118	797	1,037	1,183	1,067	987	1,205	1,198	1,195
Impedance: Gen to COL (system pu)	0.0455	0.0528	0.0433	0.0446	0.0427	0.0430	0.0433	0.0410	0.0439
Deliverable Dynamic VAR (MVAr)	**658**	**414**	**514**	**704**	**630**	**568**	**725**	**731**	**724**
Ratio of Deliverable MVArs to Qgen	59%	52%	50%	59%	59%	58%	60%	61%	61%
VARs/Impedance (System pu/pu)	246	151	239	266	250	230	278	292	273
VARs/Impedance (load pu/pu)	19%	12%	18%	20%	19%	18%	21%	23%	21%

- For each portfolio, the total resource active and reactive power ratings are calculated, along with the electrical distance (i.e., impedance) to the center of load (COL), and the amount of dynamic reactive power that can be delivered to the load centers after accounting for reactive losses along the distance.
- The analysis shows that only 50%-61% of the reactive power that is generated by the resources can actually be delivered to the load centers. Portfolios with higher percentages are closer to the load centers.

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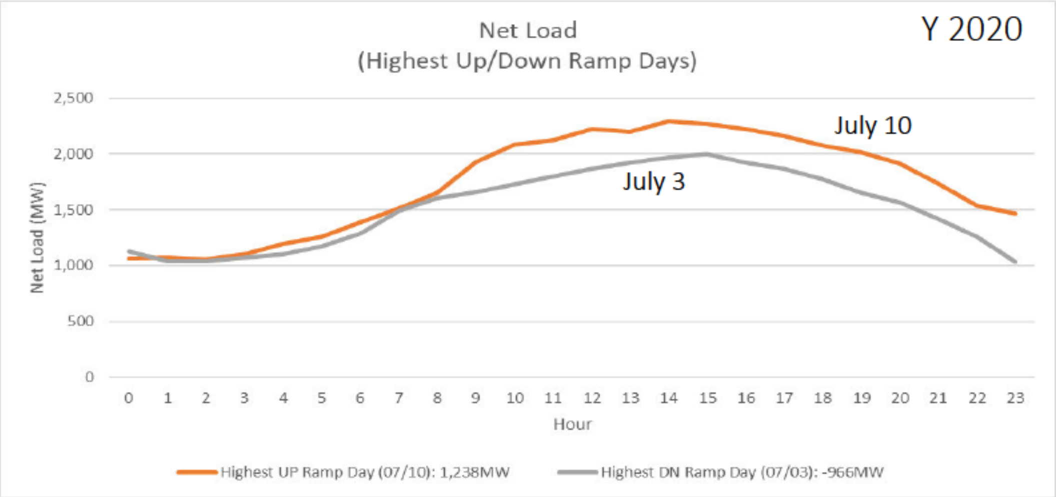
Power Ramps

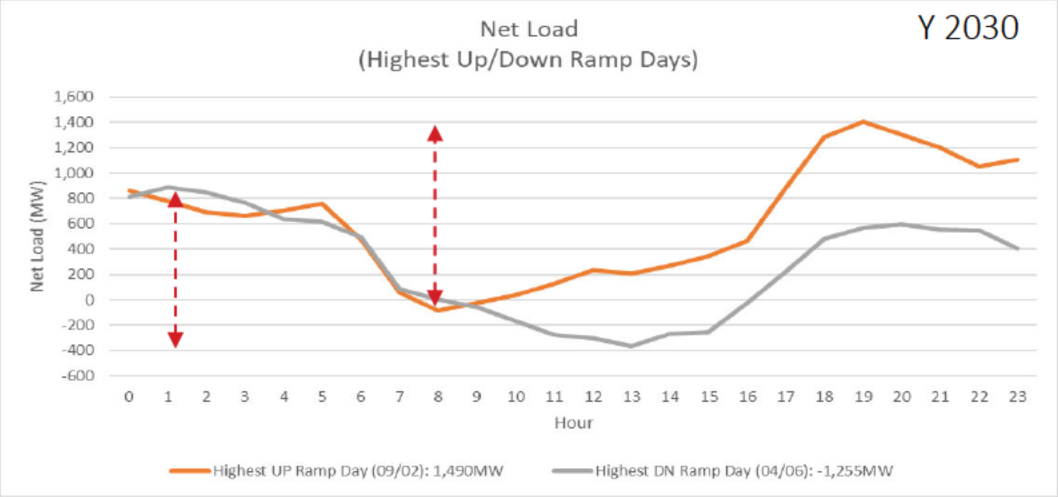
- The electric power industry has documented over the past decade an expected change in the hourly load profiles as intermittent renewable penetration of solar and wind resources increases. This has been dubbed the "Duck Curve".
- System operation is challenged during periods of high-power ramp rates. This has prompted CAISO and later MISO to adopt a new ancillary service product called Ramping Product, with the objective of acquiring fast ramping resources that can be committed and dispatched rapidly to balance the system supply and demand during these periods of high-power ramps.
- Power ramps can occur at different time scales:
  - Intra-hour ramping: intermittency of renewable resources due to cloud cover or wind bursts. These ramps can be quantified at a second, minute, 5-min, and 10-min basis. These ramps can be mitigated by procuring additional fast regulation reserves including energy storage.
  - Hour to hour: changes in power output between two consecutive hours.
  - Multi-Hour during a day: sustained increase or decrease in power output across several successive hours in a day.
- Hourly and daily power ramps can be partially mitigated by properly forecasting and scheduling these ramps in the day-ahead and real-time markets. However, any unscheduled hourly ramps will affect control area performance and have to be mitigated within the control area. Energy is scheduled with MISO in the day-ahead hourly market and in the real-time 5-minute market. Schedules are submitted up to 38 hours ahead of the actual hour time for the day-ahead market and 30 minutes for the real time market.

Net Load Power Ramps

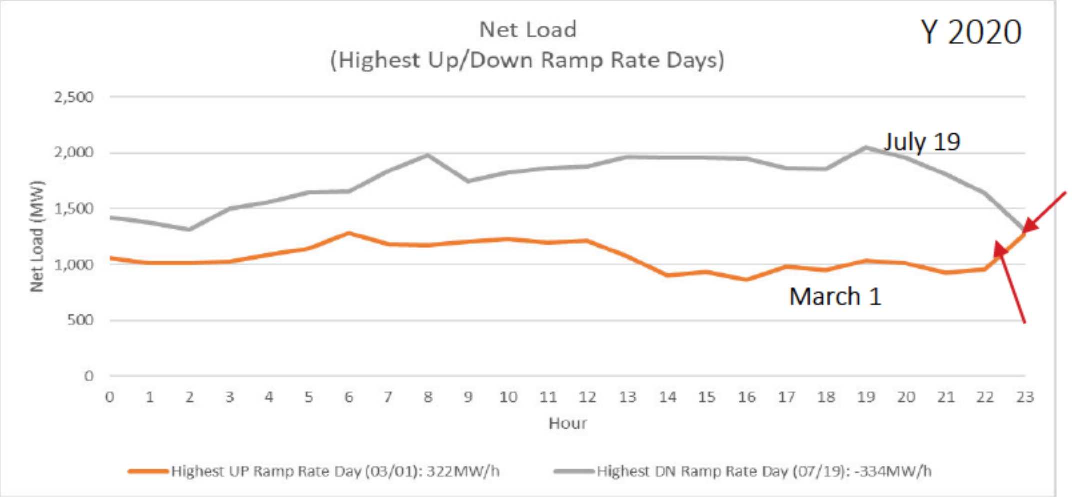
Portfolio E (without Storage/Peakers Dispatch)

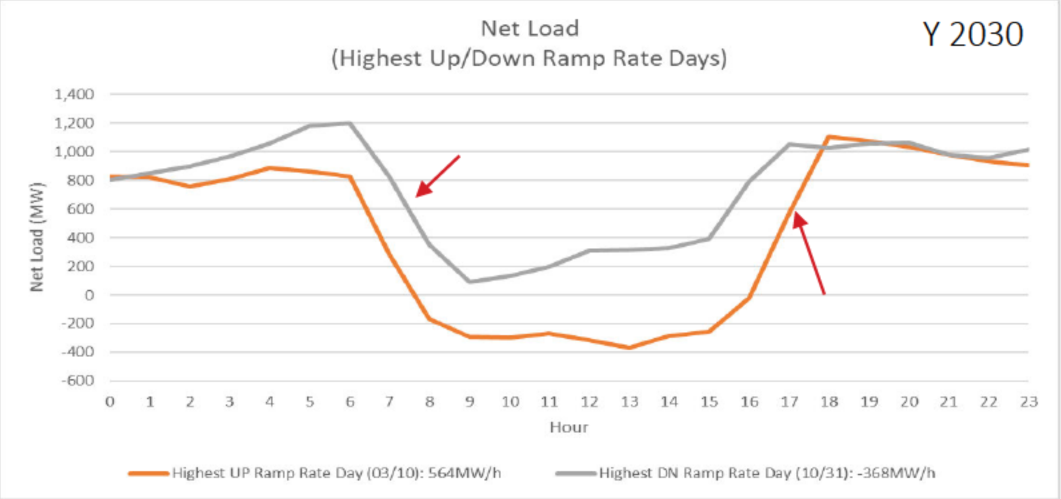
Highest Up/Down Ramp Days





Highest Up/Down Ramp Rate Hours





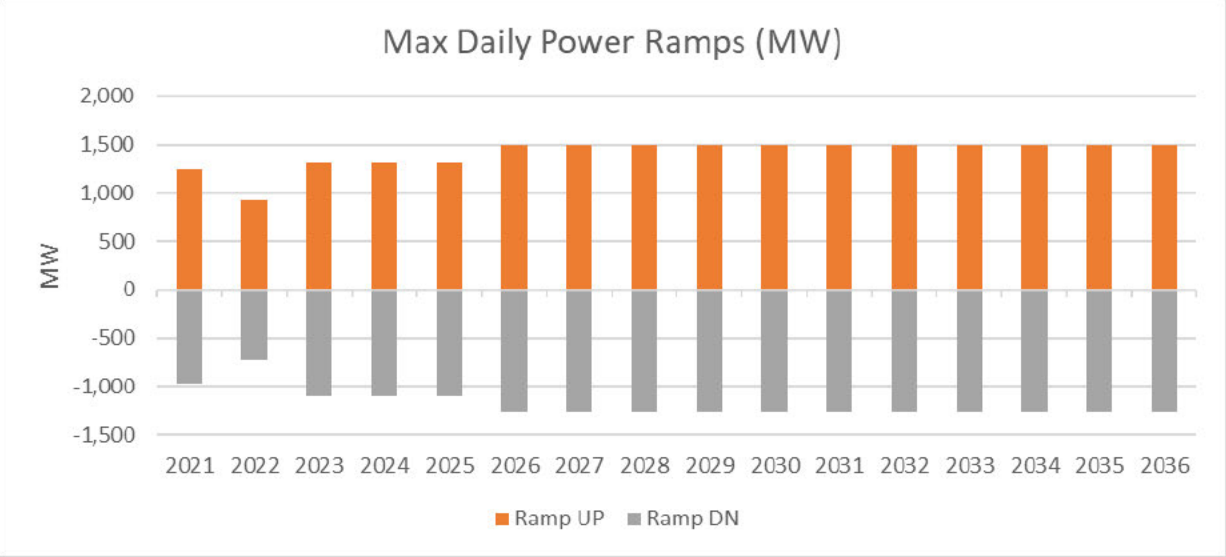
Significant change in Net Load profile from a conventional shape in 2020 to a "Duck Curve" in 2030.

Only the solar and wind resources within NIPSCO service area are included in the above analysis

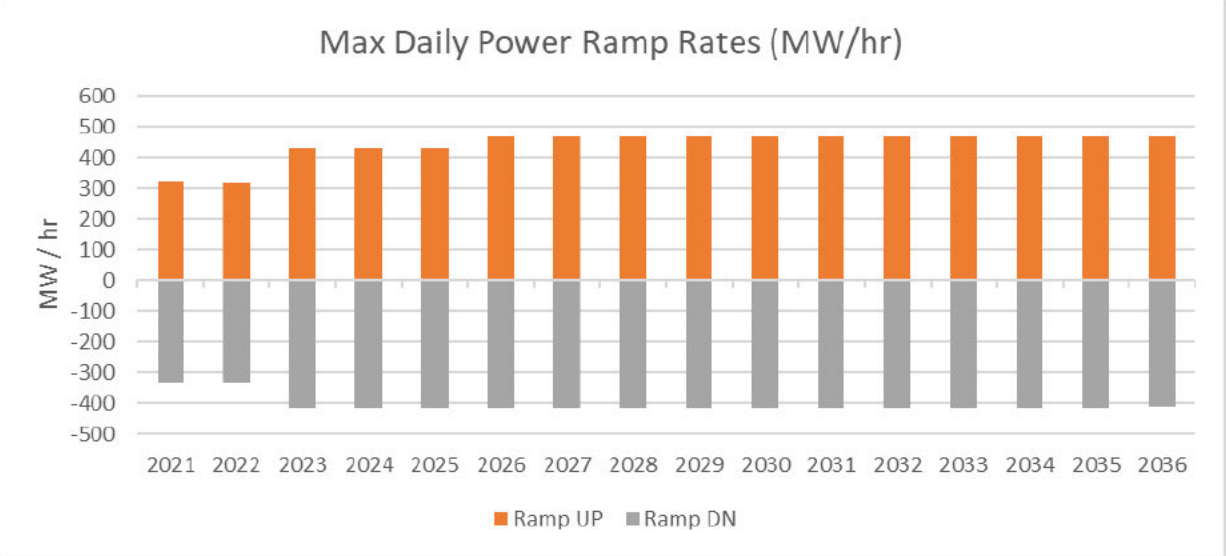
Net Load Power Ramps

Portfolio E (without Storage/Peakers Dispatch)

Year	Ramp UP	Ramp DN	Ramp Rate UP	Ramp Rate DN
2021	1,238	-966	322	-334
2022	929	-733	319	-332
2023	1,309	-1,101	431	-415
2024	1,308	-1,101	430	-414
2025	1,307	-1,101	430	-414
2026	1,490	-1,255	468	-414
2027	1,490	-1,255	468	-414
2028	1,490	-1,255	468	-414
2029	1,490	-1,255	468	-414
2030	1,490	-1,255	468	-413
2031	1,489	-1,255	467	-413
2032	1,489	-1,255	467	-413
2033	1,489	-1,255	467	-413
2034	1,489	-1,255	467	-413
2035	1,489	-1,255	467	-413
2036	1,489	-1,255	467	-413



Ramping Category	2020		2030		Increased MW 2030 vs 2020
	MW	%Peak	MW	%Peak	
1-hr Up	306	13.1%	468	20.5%	162
1-hr Down	-222	9.5%	-413	18.1%	191
Day Up	1,044	44.6%	1,489	65.2%	445
Day Down	-852	36.4%	-1,255	54.9%	403



Net Load Power Ramps (Y2030 vs Y2020)

Portfolio	Solar	Wind	Solar + Storage	Day Ramping Up (MW)	Day Ramping Down (MW)	1hr Ramping Up (MW)	1hr Ramping Down (MW)	Peaker/Storage (MW)	Forecast Error 90th Percentile	Excess Ramping Capability (MW)
2020	**24**	**406**	**0**	**1,044**	**-852**	**306**	**-222**	**155**	**37**	**118**
A	1,374	606	450	1,540	-1,450	558	-413	270	363	-93
B	1,224	606	0	1,368	-1,163	445	-413	135	281	-146
C	1,124	606	0	1,305	-1,101	430	-413	460	262	198
D	1,524	606	450	1,666	-1,576	605	-413	270	392	-122
E	1,374	606	0	1,490	-1,255	468	-413	605	309	296
F	1,224	606	0	1,368	-1,163	445	-413	570	281	289
G	1,574	606	450	1,708	-1,618	621	-413	270	401	-131
H	1,374	806	0	1,518	-1,394	522	-497	705	325	380
I	1,374	806	0	1,518	-1,394	522	-497	698	325	373

Resources insdie NIPSCO service territory only; Peaker/Storage includes stand-alone storage and 50% of flexible combined cycle capacity

- Balancing areas are required per BAL-003 to comply with CPS1 and CPS2. CPS2 is a monthly standard intended to limit unscheduled flows. It requires compliance better than 90% that the average ACE will remain below a threshold over all 10-min intervals in the month. For a balancing area with a peak load of 2500MW, the threshold is around 37MW. NIPSCO is a local balancing area under MISO but does not carry any ACE performance requirements currently.
- A small percentage (≈30%) of the hourly ramps in Net Load can be forecasted an hour ahead using a persistent forecast method and thus scheduled in the real time market. Example, Portfolio E has total 1-hour ramp up of 468MW while its forecast error is 309MW, or 66%.
- The unforecasted changes in renewable resource outputs should be mitigated using fast ramping resources.
- Portfolios ranked according to their ability to mitigate the unforecasted power ramps from best to worst are: H, I, E, F, C. Other portfolios require additional flexible ramping resources to mitigate the impacts of the renewable power ramps.

Reliability Assessment Study

Content:

Series of filters to Assess System Reliability

Importance and Impacts of Short Circuit Strength

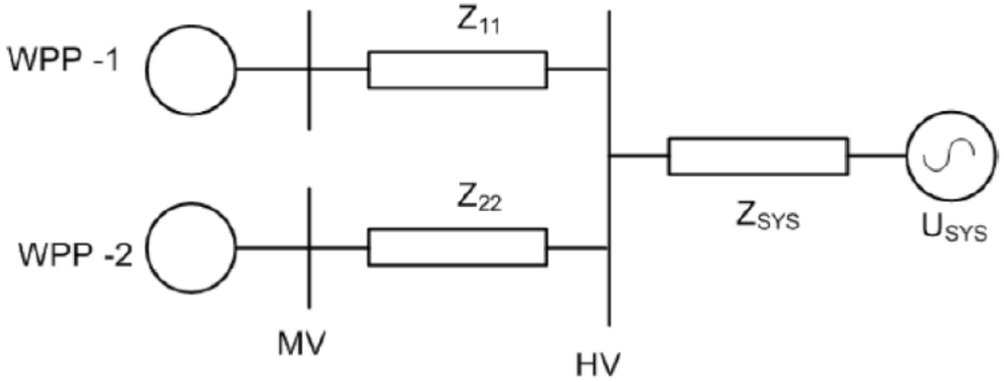
- **Importance:**

- Short Circuit MVA (SCMVA) is a measure of the strength of a bus in a system. The larger SCMVA, the stronger the bus. That indicates the bus is close to large voltage sources, and thus it will take large injections of real or reactive power to change its voltage. SCMVA changes depending on grid configuration and on-line resources. The lowest SCMVA is usually utilized for engineering calculations.
- When IBRs are interconnected to a system, it is desirable to maintain a stable bus voltage irrespective of the fluctuation of the IBR's output. Similarly, grid following (GFL) inverters rely on stable voltage and frequency to synchronize to the grid using their phase locked loops (PLL).
- The maximum allowable size of IBR desiring to interconnect to a bus is limited to a fraction of the bus's short circuit MVA, say less than 20-50%. This is expressed as Short Circuit Ratio (SCR) of the ratio of SCMVA to the rating of the IBR. This will translate to SCR of 2-5.
- When multiple IBRs are interconnected at a close electrical distance, their controls interact, and the impact of system voltages will increase. Thus, a modified measure was adopted to be ESCR (Effective SCR) to capture this interaction.

- **Impact:**

- When conventional power plants with synchronous generators are retired and/or the system tie-lines are severed, the short circuit currents will dramatically decline. IBRs are not a substitute because their short circuit contribution is limited, and also the phase of their current (real) is not aligned with typical short circuit currents (reactive).
- Declining SCMVA and increasing IBRs will eventually violate the ESCR limits, requiring either a prohibition on additional IBR interconnections, or provisioning additional mitigation measures.
- Mitigations can come in the form of optimal placement of IBRs to avoid clustering them in a manner that violates the ESCR limits, provisioning synchronous condensers, or requiring inverters to have grid-forming (GFM) capability.

Short Circuit Strength – Equivalent Short Circuit Ratio



$$ESCR_i = \frac{S_i}{P_i + \sum_j IF_{ji} * P_j}$$

where $IF_{ji} = \frac{\Delta V_j}{\Delta V_i}$ is the interaction factor between buses i and j and can be calculated using Zbus.

Pi and Pj are the inverter ratings at buses i and j respectively, while Si is the minimum short circuit MVA at bus i.

Optimal Placement of IBRs from Short Circuit perspective to avoid ESCR limitation:

$$MAXIMIZE \sum_{j \in buses} P_j$$

Subject to $\sum_j IF_{ji} * P_j \leq \frac{S_i}{ESCR\ Threshold}$

$$P_j \geq 0$$

Placement of IBRs in Portfolios A to I

- NIPSCO provided a list of locations of the planned IBRs as follows:
  - The resources in each portfolio (A-I) are located at buses with Queued projects and POIs. The study distributed them among these POIs while respecting the ICAP MW to the extent possible (next slide).
  - The map marks the location of the IBRs with yellow star and the location of the 2 planned synchronous condensers with the purple stars.
  - Synchronous Condensers: 986MVA (Gibson, Bailly)
  - Islanded NIPSCO system was modeled.

[redacted]

Portfolio	Solar PV MW	Wind MW	Energy Storage MW	Thermal Gen MW	Hyrdo	IBR %
A	1,674	606	420	0	10	99.6%
B	1,224	606	135	0	10	99.5%
C	1,124	606	135	650	10	73.9%
D	1,824	606	420	0	10	99.7%
E	1,374	606	605	0	10	99.6%
F	1,224	606	270	300	10	87.1%
G	1,874	606	420	0	10	99.7%
H	1,374	806	705	0	10	99.7%
I	1,374	806	505	193	10	93.0%

Placement of IBRs in Portfolios A to I

Bus	Bus Name	kV	Closeby Bus	Project	Type	ICAP(MW) - Power flow	A	B	C	D	E	F	G	H	I
255504	17J837_INXRD	0.7	Reynolds	Indiana Crossroads	Wind	200	200	200	200	200	200	200	200	200	200
255506	17J838_INXRD	0.7	Reynolds	Indiana Crossroads	Wind	100	100	100	100	100	100	100	100	100	100
255205	17REYNOLDS	345	Reynolds	Indiana Crossroads	Solar	224	224	224	224	224	224	224	224	224	224
3	TAP1	345	TAP1	Cavalry	S+S	200	200	200	200	200	200	200	200	200	200
255490	17J643-DUNNS	0.7	RMSGS	Dunn's Bridge 1	Solar	165	165	165	165	165	165	165	165	165	165
255510	17J847-DUNNS	0.7	RMSGS	Dunn's Bridge 1	Solar	100	100	100	100	100	100	100	100	100	100
255110	17SCHAHFER	345	RMSGS	Dunn's Bridge 2	S+S	435	435	435	435	435	435	435	435	435	435
255205	17REYNOLDS	345	Reynolds	Greensboro	S+S	100	130	130	130	130	130	130	130	130	130
255205	17REYNOLDS	345	Reynolds	Brickyard	Solar	200	200	200	200	200	200	200	200	200	200
255205	17REYNOLDS	345	Reynolds	Green River	Solar P2	200	200	200	200	200	200	200	200	200	200
255205	17REYNOLDS	345	Reynolds	Gibson	Solar P2	280	280	280	280	280	280	280	280	280	280
255205	17REYNOLDS	345	Reynolds	Indiana Crossroads II	Wind	200	305	305	305	305	305	305	305	305	305
255205	17REYNOLDS	345	Reynolds	Indiana Crossroads	S+S P1	200	200			200	250	100	200	250	250
255106	17LEESBURG	345	Leesburg	Fairbanks	Solar	250	250	250	250	250	250	250	250	250	250
255106	17LEESBURG	345	Leesburg	Elliot	Solar	200	200	200	200	200	200	200	200	200	200
255205	17REYNOLDS	345	Reynolds	Project A	Wind P1	200	250			250			250	200	200
255130	17GREEN_ACRE	138	Green Acres	Project B	Storage A2	150	135			135	150	135	135	150	135
255180	17STILLWELL	138	Stillwell	Project C	Storage P2	131	131	100		200	131		200	131	131
255151	17LUCHTMAN	138	Luchtman	Project D	Storage P2	125	119	0		200	125		200	125	104
255149	17LK_GEORGE	138	Lake George	Project E	Storage P2	62.5					62.5		50	162.5	
255159	17MORRISON	138	Morrison	Project F	S+S P1	225									
255205	17REYNOLDS	345	Reynolds	Project G	S+S P1	150									
255110	17SCHAHFER	345	RMSGS	SCHAFER-A					650			300			193
255100	17BABCOCK	345		Babcock			500	500	500	500	500	500	500	500	500
255235	17BAILLY-8	22		Bailey8			486	486	486	486	486	486	486	486	486
						Outside Nipsco		434							
				Sub-Total (MW)			4,810	4,509	4,625	4,960	4,694	4,510	5,010	4,994	4,988

Gas Peaker	CC	Solar	S+S	ESS	Wind	Sync Con.	Planned	Outside

QUANTA TECHNOLOGY

Short Circuit Study Procedure

- An islanded NIPSCO system is modeled including 2 synchronous condensers.
- System Zbus matrix is calculated, and the Interaction Factor matrix is derived.
- The Effective Short Circuit Ratio (ESCR) is calculated at each bus to assess the strength of the system to integrate the combined planned and Portfolio IBRs.
- If the ESCR is above 3, the Portfolio is deemed satisfactory from a short circuit strength perspective.
- Otherwise, additional synchronous condensers are placed in the system and their sizes optimized to enable full integration of the Portfolio resources (not withstanding potential violations of other planned resources outside of the portfolio).
- The portfolios are compared based on the total MVA of the synchronous condensers that will be required to mitigate short circuit strength violations.
- Three sites for synchronous condensers were selected based on the system topology:
  - 17REYNOLDS, 17SCHAHFER, and 17BURR_OAK
- NOTE: This is a screening level analysis and is not accurate but indicative. Detailed system studies should be conducted by NIPSCO to assess the selected Portfolio in detail.

Interaction Factors (IF_{ij}) between Sites

		kV	0.7	0.7	345	0.7	0.7	345	345	345	138	138	138	138	138
		Bus #	255504	255506	3	255490	255510	255110	255205	255106	255130	255180	255151	255149	255159
kV	Bus #	Name	17J837_INXRD	17J838_INXRD	TAP1	7J643-DUNNS	7J847-DUNNS	17SCHAHFER	17REYNOLDS	17LEESBURG	GREEN_ACR	7STILLWELL	17LUCHTMAN	7LK_GEORGE	17MORRISON
0.7	255504	17J837_INXRD	0.96	0.43	0.67	0.06	0.05	0.43	0.85	0.42	0.31	0.29	0.22	0.36	0.14
0.7	255506	17J838_INXRD	0.56	0.97	0.67	0.06	0.05	0.43	0.85	0.42	0.31	0.29	0.22	0.36	0.14
345	3	TAP1	0.18	0.14	0.85	0.07	0.06	0.53	0.73	0.52	0.38	0.35	0.27	0.44	0.13
0.7	255490	17J643-DUNNS	0.10	0.08	0.46	0.97	0.25	0.77	0.41	0.41	0.57	0.41	0.43	0.67	0.08
0.7	255510	17J847-DUNNS	0.10	0.08	0.46	0.30	0.97	0.77	0.41	0.41	0.57	0.41	0.43	0.67	0.08
345	255110	17SCHAHFER	0.11	0.08	0.50	0.11	0.10	0.85	0.44	0.45	0.59	0.42	0.40	0.68	0.09
345	255205	17REYNOLDS	0.21	0.16	0.66	0.06	0.05	0.43	0.85	0.42	0.31	0.29	0.22	0.36	0.14
345	255106	17LEESBURG	0.15	0.12	0.69	0.09	0.07	0.64	0.62	0.87	0.46	0.43	0.32	0.53	0.12
138	255130	17GREEN_ACRE	0.10	0.08	0.46	0.11	0.09	0.77	0.41	0.41	0.90	0.43	0.42	0.81	0.08
138	255180	17STILLWELL	0.12	0.09	0.52	0.10	0.08	0.68	0.48	0.48	0.52	0.91	0.44	0.64	0.10
138	255151	17LUCHTMAN	0.10	0.07	0.43	0.11	0.09	0.68	0.38	0.39	0.56	0.47	0.93	0.70	0.08
138	255149	17LK_GEORGE	0.10	0.08	0.44	0.11	0.09	0.73	0.40	0.40	0.67	0.43	0.44	0.88	0.08
138	255159	17MORRISON	0.21	0.16	0.70	0.07	0.06	0.51	0.83	0.49	0.37	0.37	0.26	0.43	0.97

- Using Zbus, the degree of interaction between IBRs at different sites is shown above.
- Based on a scale of 1.0 for impact of an IBR at its bus (i), the impact of another IBR at bus (j) on bus i is shown in column i and row j. For example, impact of an IBR at 17LK_George on 17Morrison bus is only 0.08 (or 8%) the impact of an IBR at 17Morrison bus, while an IBRs at 17J837_INXRD bus has similar impact on REYNOLDS bus as one located at REYNOLDS.

ESCR Analysis – Without Mitigation

- Using the an ESCR threshold of 3, the analysis shows that ESCR is violated at each bus for all Portfolios. Therefore, all portfolios will require mitigation. This analysis did not consider the combined cycle plant or Hydrogen plants in Portfolios B, C, F, and I.
- Portfolio C does not introduce additional IBRs to those already planned and thus is excluded from this comparative analysis.
- Each Portfolio is evaluated using %Pass (percentage of IBR resources) that will pass the ESCR test. The analysis is provided for all resources and again for only those introduced by the Portfolio.

Bus	Bus Name	A	B	C	D	E	F	G	H	I
255504	17J837_INXRD	F	F	F	F	F	F	F	F	F
255506	17J838_INXRD	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
3	TAP1	F	F	F	F	F	F	F	F	F
255490	17J643-DUNNS	F	F	F	F	F	F	F	F	F
255510	17J847-DUNNS	F	F	F	F	F	F	F	F	F
255110	17SCHAHFER	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
255106	17LEESBURG									
255106	17LEESBURG									
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
255130	17GREEN_ACRE	F			F	F	F	F	F	F
255180	17STILLWELL	F	F		F	F		F	F	F
255151	17LUCHTMAN	F			F	F		F	F	F
255149	17LK_GEORGE					F		F	F	
255159	17MORRISON									
255205	17REYNOLDS	F	F	F	F	F	F	F	F	F
	Total									
	Pass (MW)	450	450	450	450	450	450	450	450	450
	Fail (MW)	3,374	2,639	2,539	3,524	3,258	2,774	3,574	3,558	3,359
	% Pass	12%	15%	15%	11%	12%	14%	11%	11%	12%
	Portfolio Only									
	Pass (MW)	0	0	0	0	0	0	0	0	0
	Fail (MW)	835	100	0	985	719	235	1,035	1,019	820
	% Pass	0%	0%	N/A	0%	0%	0%	0%	0%	0%

ESCR Analysis – With SC Mitigation

- The analysis is repeated by optimizing the mitigation using 3 potential synchronous condensers (SC) to enable each Portfolio to pass the test. For Portfolios C, F, I, the total SC MVA will be reduced by the planned synchronous generation assets (assuming they are located at places that provide similar short circuit strength as the assumed combined 3 sites in this study).
- Portfolio C does not introduce IBRs.
- The ranking of portfolios from lowest need for mitigation are:
  - F, C, B, I, E, A, H, D, G

Without Grid Forming Inverters

Portfolio	Synch Condenser (Gross) MVA	Synch. Gen (MW)	Synch Condenser (Net) MVA
A	673		673
B	260		260
C	0	650	0
D	882		882
E	646		646
F	294	300	0
G	935		935
H	810		810
I	661	193	468

ESCR Analysis – With SC Mitigation and Grid Forming ESS Inverters

- The analysis is repeated by assuming all storage systems will be equipped with grid forming inverters, and then optimizing the mitigation using 3 potential synchronous condensers (SC) to enable each Portfolio to pass the test. For Portfolios C, F, I, the total SC MVA will be reduced by the planned synchronous generation assets (assuming they are located at places that provide similar short circuit strength as the assumed combined 3 sites in this study).
- Portfolio C does not introduce IBRs.
- The ranking of portfolios from lowest need for mitigation are:
  - F, C, I, E, B, H, A, D, G

With Grid Forming Inverters for Energy Storage

Portfolio	Synch Condenser (Gross) MVA	Synch. Gen (MW)	Synch Condenser (Net) MVA
A	580		580
B	260		260
C	0	650	0
D	763		763
E	341		341
F	259	300	0
G	802		802
H	488		488
I	450	193	257

ESCR Analysis – With Mitigation (Caution)

- The analysis reveals potential issues with planned projects that should be investigated in detail at a level deeper than this screening study level.
- These correspond to the following projects:

Bus	Bus Name	kV	Project	Type	ICAP(MW) - Power flow
255504	17J837_INXRD	0.7	Indiana Crossroads	Wind	200
255506	17J838_INXRD	0.7	Indiana Crossroads	Wind	100
255490	17J643-DUNNS	0.7	Dunn's Bridge 1	S+S	165
255510	17J847-DUNNS	0.7	Dunn's Bridge 1	Solar	100

Bus	Bus Name	A	B	C	D	E	F	G	H	I
255504	17J837_INXRD	F	F	F	F	F	F	F	F	F
255506	17J838_INXRD	F	F	F	F	F	F	F	F	F
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
3	TAP1	P	P	P	P	P	P	P	P	P
255490	17J643-DUNNS	F	F	F	F	F	F	F	F	F
255510	17J847-DUNNS	F	F	F	F	F	F	F	F	F
255110	17SCHAHFER	P	P	P	P	P	P	P	P	P
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
255106	17LEESBURG									
255106	17LEESBURG									
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
255130	17GREEN_ACRE	P			P	P	P	P	P	P
255180	17STILLWELL	P	P		P	P		P	P	P
255151	17LUCHTMAN	P			P	P		P	P	P
255149	17LK_GEORGE					P		P	P	
255159	17MORRISON									
255205	17REYNOLDS	P	P	P	P	P	P	P	P	P
	Total									
	Pass (MW)	3,259	2,524	2,424	3,409	3,143	2,659	3,459	3,443	3,244
	Fail (MW)	565	565	565	565	565	565	565	565	565
	% Pass	85%	82%	81%	86%	85%	82%	86%	86%	85%
	Portfolio Only									
	Pass (MW)	835	100	0	985	719	235	1,035	1,019	820
	Fail (MW)	0	0	0	0	0	0	0	0	0
	% Pass	100%	100%	N/A	100%	100%	100%	100%	100%	100%

Reliability Assessment Study

Content:

1. Essential Reliability Services - Overview
2. NIPSCO Demand and Resource Development
3. Resource Variability Analysis
4. Modeling the Portfolios:
   i. Energy Adequacy Analysis (Islanded, Emergency)
   ii. Dispatchability
   iii. Flexibility: Inertial, Primary Frequency Response
   iv. Dynamic VAR Support
   v. Predictability of Supply
   vi. Short Circuit Strength
   vii. **Blackstart**
   viii. Locational Attributes
5. Summary of Findings

Series of filters to Assess System Reliability

Blackstart

- The power industry does not have experience of blackstarting systems served mostly by inverter-based resources. Few success stories have been reported in news media over the past 5 years:

- GE Completes First Battery Assisted Blackstart of a GE Heavy Duty Gas Turbine
  - Perryville Power Station, Entergy
  - GE 7F.03 150MW simple cycle
  - BESS 7.4MW
  - Feb 2020
- Imperial Irrigation District
  - El Centro Generating Station, Southern California
  - 44MW combined cycle
  - BESS 33MW/20MWh
  - Originally designed for grid stability and renewable smoothing
  - May 2017
- Scottish Power
  - Blackstart of wind power in world-first demonstration
  - Nov 2020
- WEMAG German Battery Park Demonstrates Successful Blackstart
  - Schwerin, a city in northern Germany
  - Combined Cycle Plant
  - BESS 5MW/15MWh
  - Originally designed for frequency regulation and other grid balancing services
  - Feb 2017
- Glendale Water & Power (GWP)
  - BESS 2MW/950kWh
  - July 2017

Grid and Resources

[redacted]

Blackstart Strategy

- Observations:
  - Five portfolios (A, D, E, G, H) do not have synchronous machines.
  - 4 Portfolios have synchronous machines (B, C, F, I)
  - 3 Portfolios have large aggregate MW stand-alone storage capability (E, H, I)
  - 2 Portfolios do not have stand-alone storage systems
  - System needs short circuit strength and inertia to function before energizing solar/wind resources.
  - All portfolios have large aggregate MWs of Solar plus storage

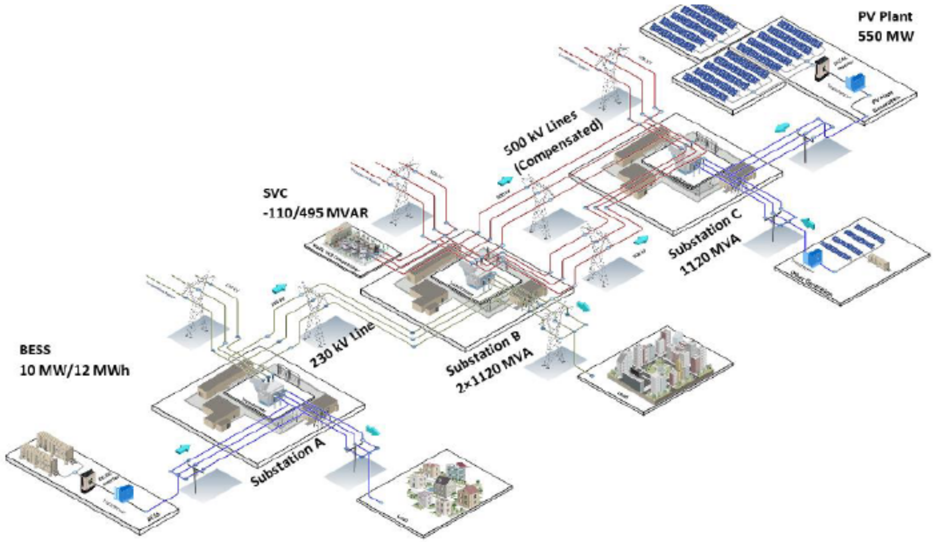
Inside NIPSCO	A	B	C	D	E	F	G	H	I
Peaker Plant	0	0	650	0	0	300	0	0	193
Synch Cond.	986	986	986	986	986	986	986	986	986
Solar	739	589	489	889	739	589	939	739	739
Solar+Storage	1085	635	635	1085	635	635	1085	635	635
Wind	605	605	605	605	605	605	605	805	805
Storage	135	0	0	135	469	135	135	569	370

- Preliminary Blackstart Strategy:
  - Energize standalone storage equipped with GFM inverters, if available
  - Portfolios B,C should specify the peaker plants to have blackstart capability
  - Find cranking paths to Synchronous Condensers and energize them.
  - Start with area around RMSGS, Babcock, Dune Acres, ..etc.
  - Energize solar plus storage sites, then solar, then wind

- Evaluation Metrics:
  - Adequacy of storage size to start the pony motors of synchronous condensers and supply the transformer inrush currents.
  - Ability of storage and synchronous condensers (real and reactive power) to blackstart other renewable resources (assume the auxiliary loads of these resources to be 5% of their rating, and that each farm is modular and can be started in steps).

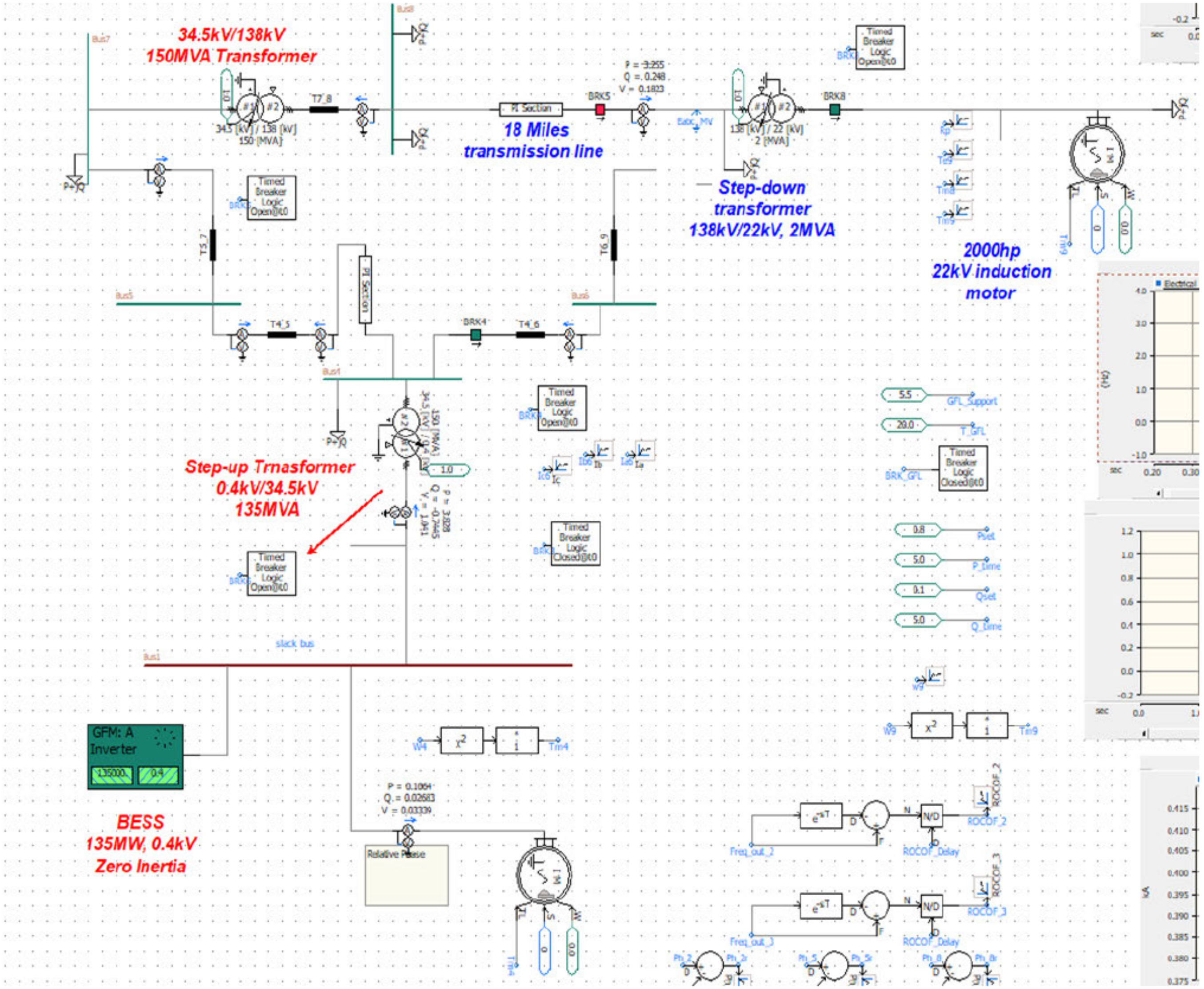
Power Plant Blackstart Studies – Key Considerations

- Modeling:
  - Sequencing of Essential Motors (Startup and Shutdown)
  - Modeling of Induction Motors (dynamic characteristics)
  - Protection system Modeling
  - Fast bus transfer
  - Battery System
  - Transformers
- Analysis:
  - Transient and steady-state simulations
- Considerations:
  - Inverter short-circuit current limitations
  - Soft-start techniques
  - Dynamic interactions
  - Frequency and Voltage control
  - Protective relay operation in view of limited short circuit currents
- Results:
  - Inverter Size (MVA, PF)
  - BESS Size (MW, MWh)
  - BESS control and protection settings
  - Transformer tap settings
  - Protection setting adjustments



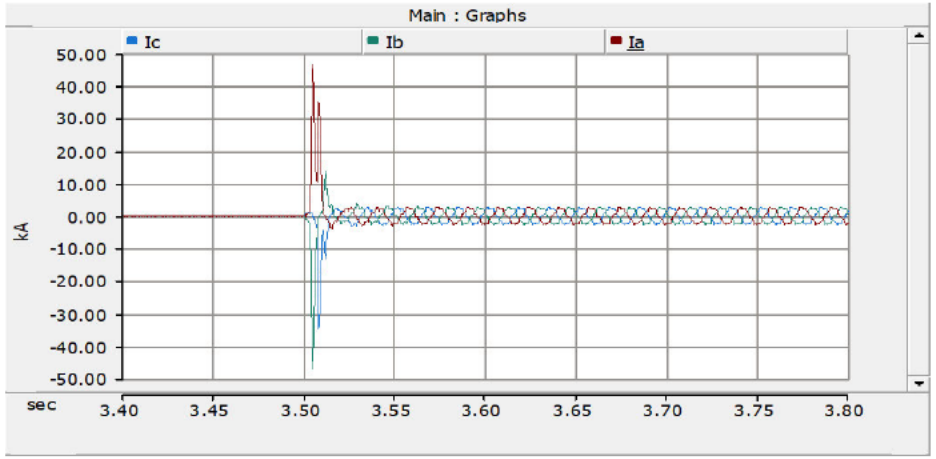
Portfolio Evaluation - Blackstart

- Using 135MW/150MVA battery to blackstart the pony motor of synchronous condensers:

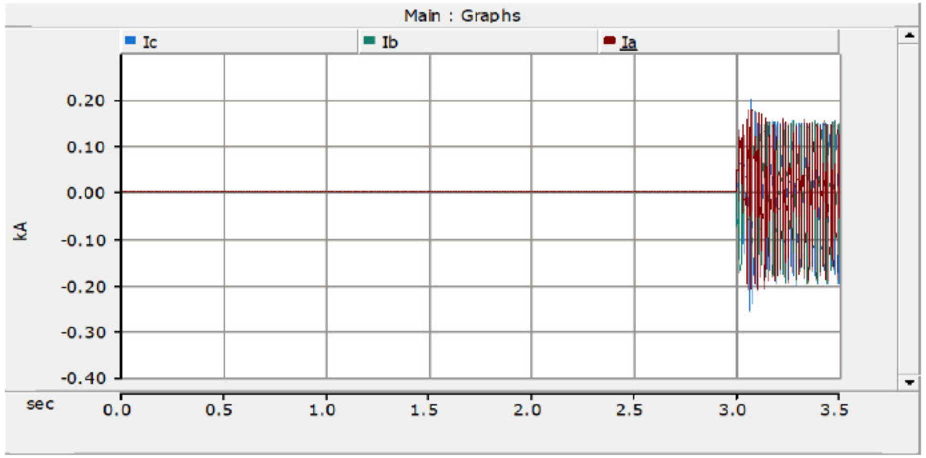


Inrush Currents

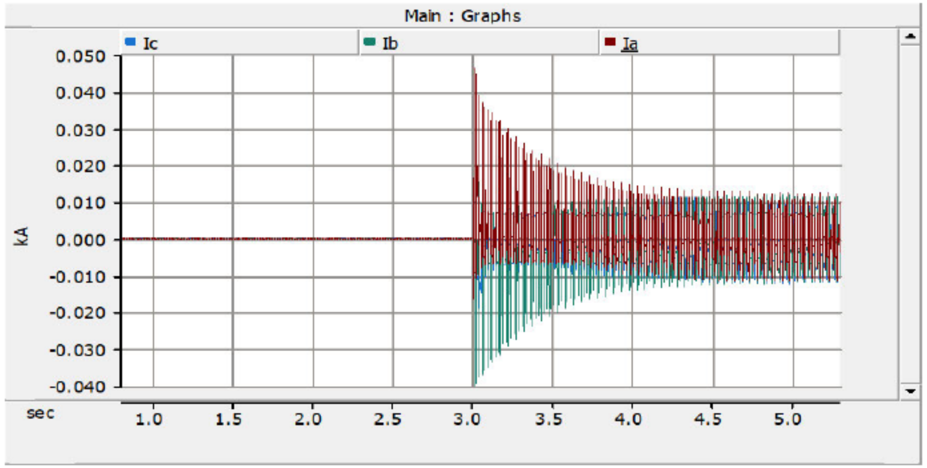
Step1: 0.4kV34.5kV XFO energization (0.4kV side)



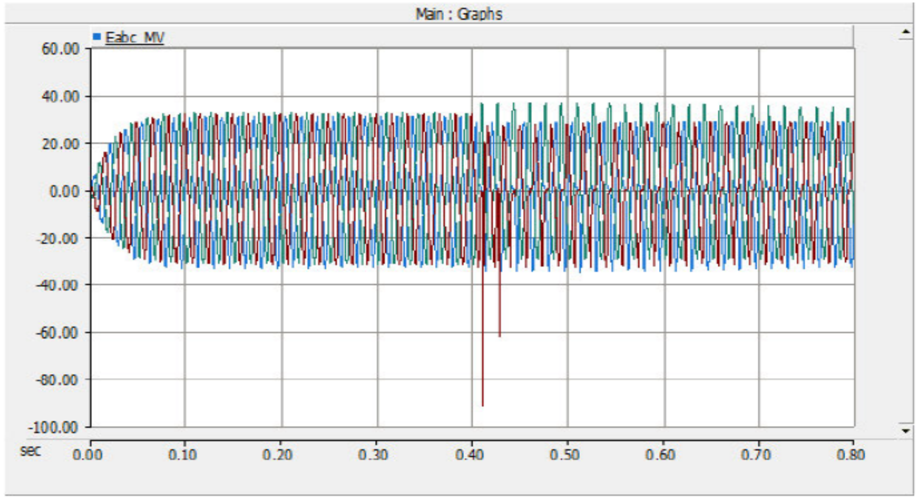
Step2 : 34.5kV/138kV XFO energization (34.5kV side)



Step3 : 138kV/22kV XFO energization (138kV side)

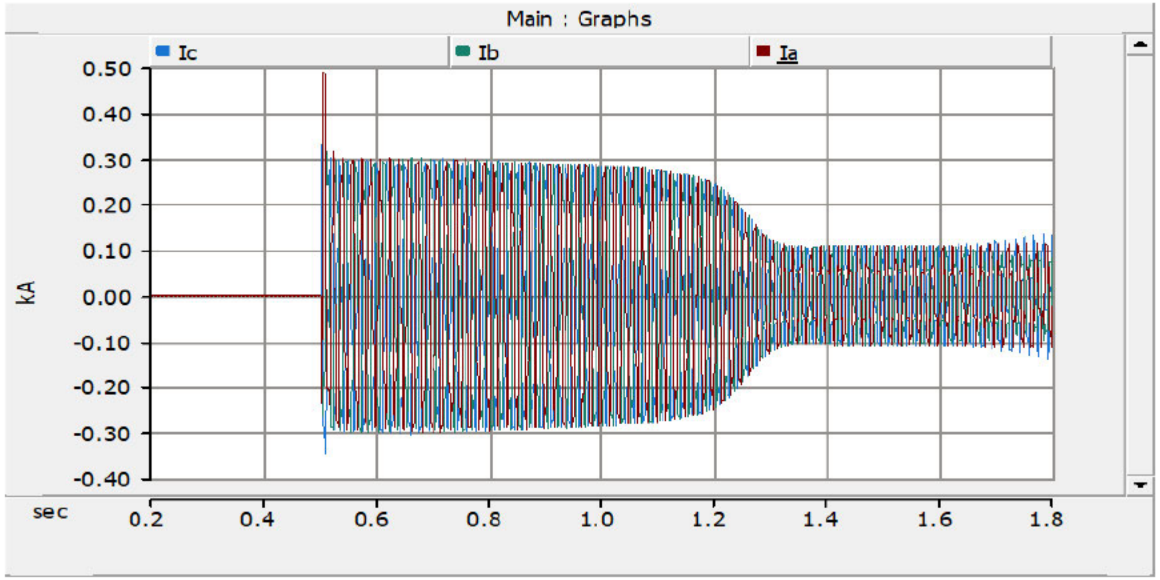


34.5kV Voltage side (TOV)

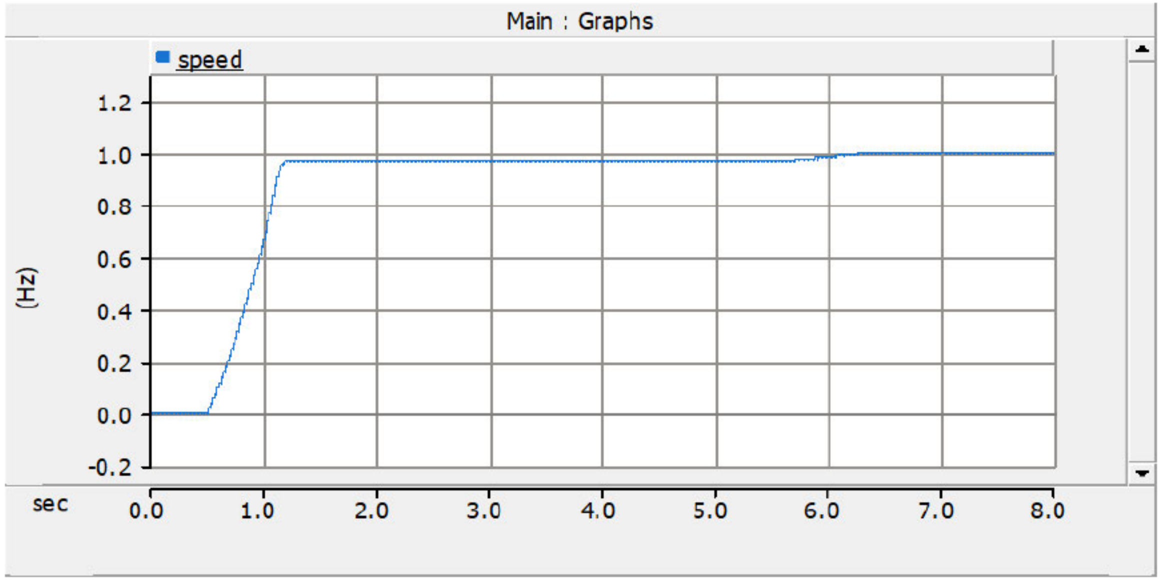


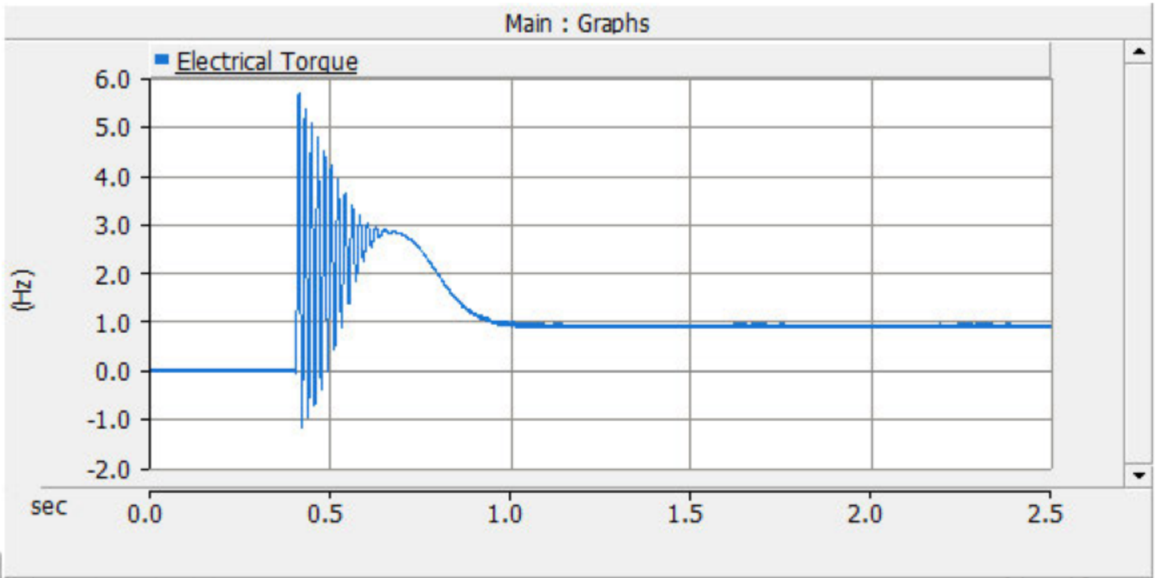
Induction Motor (Pony)

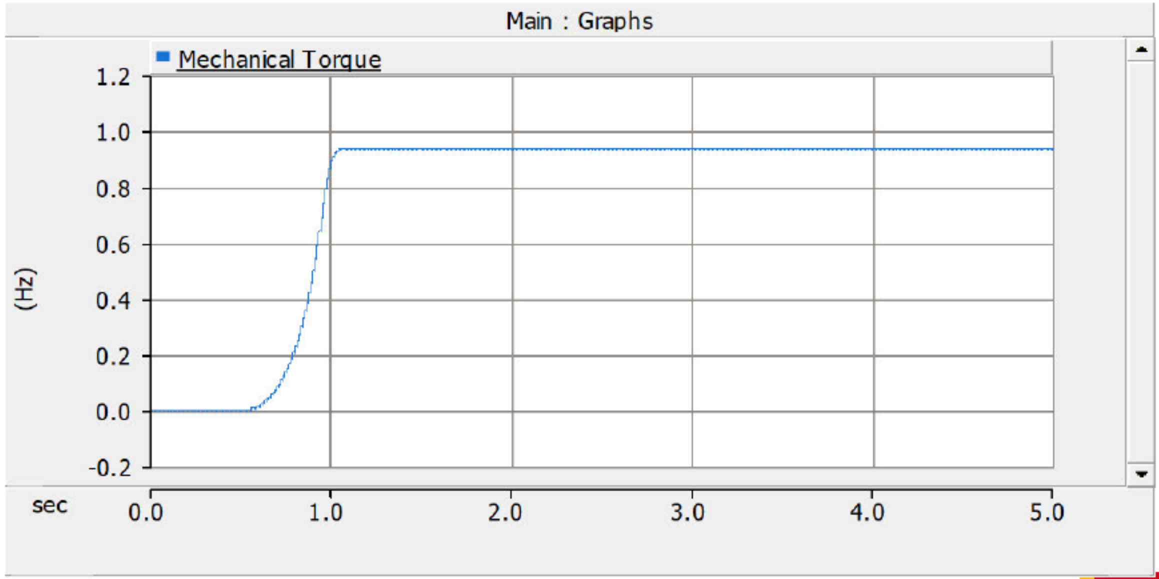
Step4 : Induction motor Inrush Current at 22kV (breaker closing)



Mechanical Speed







Check Battery Ratings

- Upon closing the breaker between the battery and the 0.4/34.5k 150MVA transformer, the inrush current is around 47kA on the 0.4kV side which translate to a rating of 33MVArs from the inverters. This level of inrush current is within the capability of the system. Note that the inrush current will depend on the breaker closing time and strategy.
- The inrush currents of energizing the 34.5/138kV transformer, the 18mile 138kV line, the 138/22kV step down transformer, and then the pony motor were 262A, 105A, 48A, and 491A on the 34.5kV, 138kV, 138kV, and 22kV respectively. The implication on the rating of the battery inverters is lower than the 33MVArs.

Blackstart Capability - Qualitative Assessment of Portfolios

- Given the very short time permitted to complete this study, proper quantitative assessments are not feasible. The following are considerations for a qualitative assessment:
  - Portfolios that do not have energy storage systems with GFM inverters and do not have Peaker Plants with blackstart capability cannot be started. So, Portfolios B will fail.
  - Portfolios that have 135MW and higher of energy storage with GFM inverters appear (from the expedient cursory analysis) to have the capability to blackstart the synchronous condensers. This applies to portfolios (D-I). Portfolio C, if its peaker plant is equipped with blackstart capability should also be able to start.
  - Portfolios without peaker plants will have a limited time to energize the system (depending on the state of charge of the batteries). Larger batteries are better. During this period, they can attempt to start facilities with solar+storage first, and then solar, and then wind near the major load centers. The synch condensers provide the reactive power, and the battery stabilize the frequency.
- From a risk perspective, it appears that the follow is the ranking of the Portfolios:
  - F and I are the best. They have both peaker plants and storage.
  - C next.
  - E, H next due their large storage size
  - G, D, A next
  - B fails to blackstart.

Reliability Assessment Study

Content:

1. Essential Reliability Services - Overview
2. NIPSCO Demand and Resource Development
3. Resource Variability Analysis
4. Modeling the Portfolios:
   i. Energy Adequacy Analysis (Islanded, Emergency)
   ii. Dispatchability
   iii. Flexibility: Inertial, Primary Frequency Response
   iv. Dynamic VAR Support
   v. Predictability of Supply
   vi. Short Circuit Strength
   vii. Blackstart
   viii. **Locational Attributes**
5. Summary of Findings

Series of filters to Assess System Reliability

Locational Attributes – Number of Evacuation Paths

- The evacuation paths from each site are tabulated based on the grid topology.
- For each site, the number of viable paths based on the site ICAP (MW) are calculated.
- Next step is to assess the average paths for each portfolio and rank them.

				Number of Evacuation Paths				Ratings MVA (average)				Evac Paths
Name	Connected	Technology	ICAP Rounded (MW)	765kV	345kV	138kV/161kV	≤69kV	765kV	345kV	138kV/161kV	≤69kV	
Indiana Crossroads	255504	Wind	200	[redacted]								7
Indiana Crossroads	255506	Wind	100									7
Indiana Crossroads	255205	Solar	224									7
Cavalry	1111	Solar + Storage	200									2
Dunn's Bridge 1	255490 255510	Solar	265									2
Dunn's Bridge 2	255110	Solar + Storage	435									6
Greensboro	306902	Solar + Storage	100									8
Brickyard	254521	Solar	200									4
Green River	340566	Solar	200									4
Gibson	249510	Solar	280									8
Indiana Crossroads II	255205	Wind	200									7
Indiana Crossroads	255519	Solar + Storage	200									7
Fairbanks	248773	Solar	250									5
Elliot	253520	Solar	200									3
Project A	255205	Wind	200									7
Project B	255130	Stand-Alone Storage	150									3
Project C	255180	Stand-Alone Storage	131									3
Project D	255151	Stand-Alone Storage	125									2
Project F	255149	Stand-Alone Storage	62.5									9
Project E	255159	Solar + Storage	225									3
Project G	348796	Solar + Storage	150									2
Schafer	255110	Gen	650									6

Locational Attributes – Portfolio Analysis

- For each portfolio, a metric of the average number of paths to evacuate the portfolio resources is calculated. Only resources in each portfolio are considered and not the previously planned resources.
- Portfolio A has an average of 5 evacuation paths while Portfolio B has 3.
- The ranking from highest evacuation paths to lowest is:
  - H, C, I/F, A, G, E, D, B

	A	B	C	D	E	F	G	H	I
7	200	200	200	200	200	200	200	200	200
7	100	100	100	100	100	100	100	100	100
7	224	224	224	224	224	224	224	224	224
2	200	200	200	200	200	200	200	200	200
2	265	265	265	265	265	265	265	265	265
6	435	435	435	435	435	435	435	435	435
8	130	130	130	130	130	130	130	130	130
4	200	200	200	200	200	200	200	200	200
4	200	200	200	200	200	200	200	200	200
8	280	280	280	280	280	280	280	280	280
7	305	305	305	305	305	305	305	305	305
7	200			200	250	100	200	250	250
5	250	250	250	250	250	250	250	250	250
3	200	200	200	200	200	200	200	200	200
7	250			250			250	200	200
3	135			135	150	135	135	150	135
3	131	100		200	131		200	131	131
2	119	0		200	125		200	125	104
9					62.5		50	162.5	
3									
2									
6			650			300			193
	Gas Peaker	CC	Solar	S+S	ESS	Wind	Sync Con.	Planned	Outside
MW-Path	4,186	300	3,586	4,555	3,406	2,760	5,005	5,706	5,221
Avg Paths	5.0	3.0	5.5	4.6	4.7	5.2	4.8	5.6	5.2

Reliability Assessment Study

Content:

Series of filters to Assess System Reliability

Summary of Findings (1/3)

- The following reliability assessments were performed for all 9 portfolios:

System Condition	Reliability Assessment
Normal	• deliverability of dynamic reactive power to load centers • short circuit strength • predictability of portfolio output • increased need for regulation reserves • geographic location
Emergency – Max Gen	• energy Adequacy – Need for energy imports
Isolated	• blackstart and restoration • short circuit strength • ability to control frequency (inertial and primary frequency response) • power ramping capability • energy adequacy to serve the critical demand of customers.

Summary of Findings (2/3)

- Screening studies indicate the potential need for the following reliability mitigations:

	A	B	C	D	E	F	G	H	I
Equip Stand-alone ESS with GFM inverters	✓	✓	✓	✓	✓	✓	✓	✓	✓
Equip Synch Gen with Blackstart capability			✓			✓			✓
Additional Power Mitigations (MW)[2]	**259**	**387**	**380**	**260**	**41[1]**	**249**	**261**	**46[1]**	**46[1]**
Increased Freq Regulation	54	37	34	58	41	37	59	46	46
Address Inertial Response Gaps	155	277	157	160	0	79	171	0	0
Address Primary Response Gaps	259	387	380	260	0	249	261	0	19
Firm up Intermittent Renewable Forecast	93	146	0	122	0	0	131	0	0
Enhance blackstart capability	135	270	0	135	0	0	135	0	0
Install Additional Synch Condensers (MVAr)	**580**	**260**	**0**	**763**	**341**	**0**	**802**	**488**	**257**

[1] Can utilize existing portfolio storage to provide frequency regulation. No need for additional storage.

[2] Requires fast frequency response within 100ms. Can be in the form of battery storage, super capacitors, or appropriately upsized combustion engines or gas turbines. Blackstart will require long duration for the energy component (4 hours or higher).

Summary of Findings (3/3)

- The 9 Portfolios are ranked as follows:

	Year 2030		A	B	C	D	E	F	G	H	I
1	Blackstart	Qualitative Assessment of Risk of not Starting	1/2	0	1	1/2	1/2	1	1/2	1/2	1
2	Energy Adequacy	Load Growth not Served during system Emergency (avg %)	1/2	1	1	0	1	1	0	1	1
		Energy Not Served when Islanded (Worst 1-week) %	1/2	1/2	1	1/2	1/2	1	1/2	1/2	1
3	Dispatchability and Automatic Generation Control	Dispatchable (VER Power Penetration %)	1/2	1	1	0	1/2	1	0	1/2	1/2
		Increased Freq Regulation Requirement (% Peak Load)	1/2	1	1	1/2	1	1	1/2	1/2	1/2
		1-min Ramp Capability (%CAP)	1	1	1	1	1	1	1	1	1
		10-min Ramp Capability (%CAP)	0	1/2	1/2	0	1/2	1/2	0	1/2	1/2
4	Operational Flexibility and Frequency Support	Inertia (s)	1/2	1	1	1/2	1/2	1	0	0	1/2
		Inertial Gap FFR (%CAP)	0	0	0	0	1	1/2	0	1	1
		Primary Gap PFR (%CAP)	0	0	0	0	1	0	0	1	1/2
5	VAR Support	Dynamic VAR to load Center Capability (%CAP)	1	1	1/2	1	1	1	1	1	1
6	Location	Average Number of Evacuation Paths	1	1/2	1	1	1	1	1	1	1
7	Predictability and Firmness	Ramping Capability to Mitigate Forecast Errors (+Excess/-Deficit) (%VER MW)	1/2	1/2	1	1/2	1	1	1/2	1	1
8	Short Circuit Strength	Required Additional Synch Condensers (%Peak Load)	0	1/2	1	0	1/2	1	0	1/2	1/2

1	Blackstart	0.50	0.00	1.00	0.50	0.50	1.00	0.50	0.50	1.00
2	Energy Adequacy	0.50	0.75	1.00	0.25	0.75	1.00	0.25	0.75	1.00
3	Dispatchability and Automatic Generation Control	0.50	0.88	0.88	0.38	0.75	0.88	0.38	0.63	0.63
4	Operational Flexibility and Frequency Support	0.17	0.33	0.33	0.17	0.83	0.50	0.00	0.67	0.67
5	VAR Support	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00
6	Location	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	Predictability and Firmness	0.50	0.50	1.00	0.50	1.00	1.00	0.50	1.00	1.00
8	Short Circuit Strength	0.00	0.50	1.00	0.00	0.50	1.00	0.00	0.50	0.50

Cumulative core	4.17	4.46	6.71	3.79	6.33	7.38	3.63	6.04	6.79
Percent Score (out of possible 8)	52%	56%	84%	47%	79%	92%	45%	76%	85%
			3		4	1		5	2

1	Portfolio passes the screening test
½	Portfolio requires minor to moderate mitigation measures
0	Portfolio requires significant mitigation measures

Team

Hisham Othman, PhD

Hisham Othman, PhD, *EXECUTIVE ADVISOR, Vice President, Transmission & Regulatory,* has almost 30 years of technical and managerial experience in the electricity sector with strong emphasis on power system dynamics and controls, flexible AC transmission, operational IT, grid integration of renewables and energy storage, and business strategy and startup. Hisham leads the transmission and regulatory compliance consulting services team, providing advanced power system technical and economic studies to help customers address their evolving and challenging business needs.

Vice President
Transmission & Regulatory

Rahul Anilkumar

Rahul Anilkumar, *SENIOR ADVISOR and Manager of Advanced Transmission Solutions, Transmission & Regulatory,* has been active in the power industry since 2012. His primary role as transmission and distribution planner has allowed him to work with several ISO and RTO planning regions. His experience includes research and development in the fields of transmission and distribution planning, renewable integration, and software development. He has completed multiple internships in the fields of data center design, automation, and power quality.

Senior Advisor
Transmission & Regulatory

Henry Chao, PhD

Henry Chao, PhD, *EXECUTIVE ADVISOR, Vice President of RTO/ISO Markets, Transmission & Regulatory*, has over 28 years of leadership and technical management experience in delivering technology solutions and professional services to the electric utility industry with a focus on public policy development, renewable interconnection, grid reliability and resiliency, system planning, operations, engineering, project development, power market efficiency, and regulations. Dr. Chao has a strong academic background, including a PhD in Electrical Engineering from Georgia Institute of Technology and Executive MBA training programs at Duke and Harvard.

Vice President
RTO/ISO Markets

Ralph Masiello, PhD

Ralph Masiello, PhD, *INDUSTRY ADVISOR, Strategy and Business Innovation,* provides support to our partners in the areas of wholesale market analysis and system performance, energy storage, distributed energy resources, and strategic planning. He received his BS, MS, and PhD in Electrical Engineering from the Massachusetts Institute of Technology (MIT) where he worked on the very early applications of modern control and estimation theory to electric power systems and the developments of the first state estimators for transmission operations. Ralph also led the teams that developed the first utility dispatcher training simulators, and he led the organization that developed the early commercial ISO systems for market and reliability operations.

Industry Leadership
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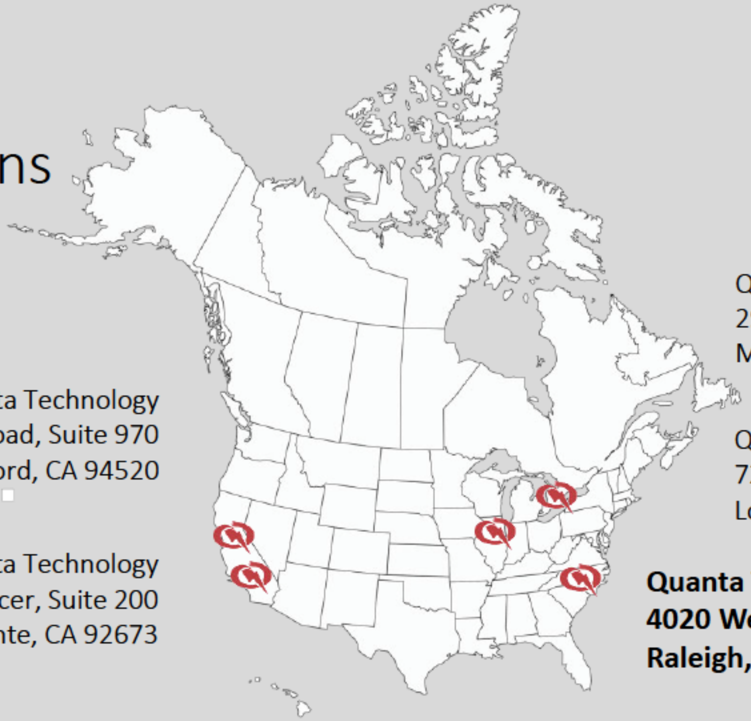
Thank you!

Office Locations



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