

# Guidelines for Linking Power Flow Analysis with Production Cost Modeling Tools for Integrated Strategic System Planning



**Needs, Screening Methods, and Best Practices**

January 2024

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# Abstract

Traditional transmission reliability assessments are performed separately from operational assessments such as production cost modeling (PCM) studies that analyze future generation dispatch and transmission system congestion. Additionally, transmission reliability assessments currently consider only a few peak, off-peak, and shoulder operating conditions to identify system risks. Particularly as system penetration of variable renewable generation and electrification of end-use processes increases, this process can be inadequate. The traditional approach may fail to capture stressed operating conditions, and the system dispatch used for modeling the selected few operating conditions may not be reflective of actual future conditions.

Linking PCM studies with transmission reliability assessments can help transmission planners identify reinforcement options that can benefit both reliability as well as system operating costs. As such, an integrated planning process that links PCM assessment with power flow studies is important. This is highlighted in EPRI's Integrated Strategic System Planning (ISSP) initiative.

Linking transmission system reliability assessments with PCM studies requires transmission planners to analyze PCM study results to screen for possible stressed operating conditions and create power flow cases that are reflective of those operating conditions. While this can be a time intensive process requiring an understanding of screening methods and creating automated processes for linking the tools used for transmission reliability analysis and PCM studies, it is a critical step in the overall integrated planning process. This technical report documents the screening methods and processes that were used as a part of the ISSP initiative to link power flow analysis to PCM study results to evaluate transmission system reliability and better understand potential reinforcement options for robust planning.

## Keywords

Integrated system planning; production cost modeling; scenario screening; transmission reliability assessment; power flow creation

# Executive Summary

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**Product Type:** Technical Update

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**Primary Audience:** Electric company staff engaged in long-term generation portfolio resource planning, transmission planning, distribution planning, end-use technology planning, integrated resource planning, decarbonization planning, and/or corporate strategy and risk management.

**Secondary Audience:** Regulators, policy makers, ISO/RTO staff, reliability organization staff, and others who are interested in integrated system planning strategy and novel modeling approaches for decarbonization planning.

## RESEARCH OVERVIEW

This report documents the needs, methods, and best practices for linking power flow analysis studies with production cost modeling assessments as a part of an integrated planning process. The research documented in this report is a part of EPRI's broader Integrated Strategic System Planning Initiative that outlines the process of linking different aspects of resource expansion planning using a consistent set of assumptions. This report documents the methods and processes that were used to ensure that the results from the production cost modeling assessment can be used to inform the transmission system reliability analysis that uses power flow assessments. This technical report provides an overview of the:

1. screening methods used to identify scenarios for power flow analysis from the PCM results;
2. the process for mapping load and dispatch data from PCM studies to the power flow case, and updating the power flow cases to represent future operating conditions; and
3. best practices for ensuring that the developed cases is ac feasible and well conditioned.

# Executive Summary

## WHY THIS MATTERS

This research provides detailed guidelines on how PCM assessments can be linked with transmission reliability studies that rely on power flow analysis. Linking these different studies are an important step in an integrated planning process, and the methods and best practices documented here are expected to help transmission planners in adopting an integrated planning process.

## HOW TO APPLY RESULTS

The methods presented here are generalizable and are independent of simulation software used for PCM assessments or power flow analysis. Planners are encouraged to review this report and try the methods outlined here for creating power flow cases or linking their PCM assessments to their steady state transmission reliability assessments.

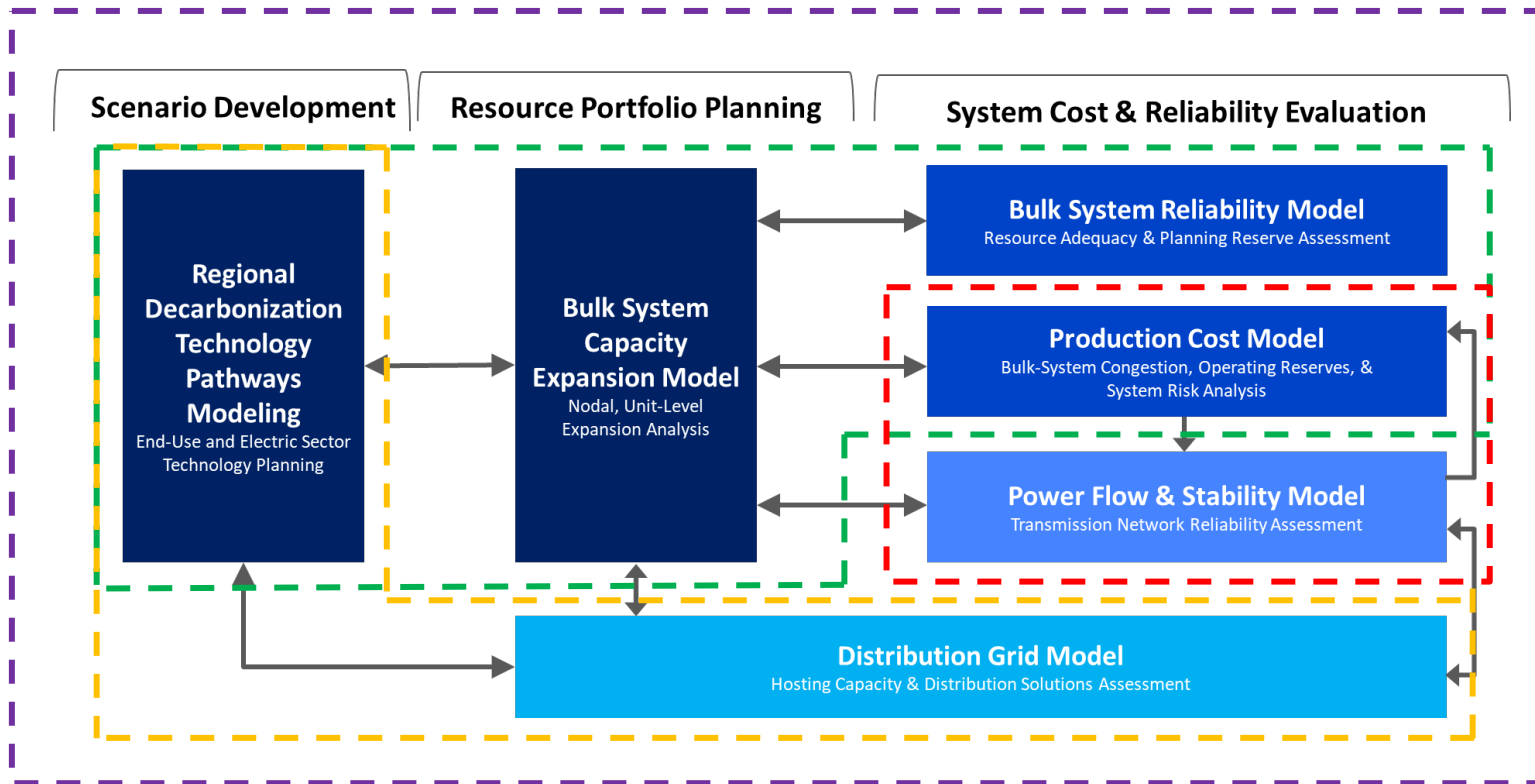
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- Implementing Integrated System Planning (ISP) Interest Group. EPRI Contact: Nidhi Santen, [nsanten@epri.com](mailto:nsanten@epri.com)
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**PROGRAMS:** Transmission Planning (P40), Bulk System Integration of Renewables and Distributed Energy Resources (P173), Electricity Market Design and Operation (P246)

# EPRI Integrated Strategic System Planning (ISSP) Initiative Technical Report Series



Integrated Strategic System Planning Initiative: Modeling Framework, Demonstration Study Results, and Key Insights (Product ID 3002028640)

Linking Capacity Expansion, Resource Adequacy, and Production Cost Modeling Tools for Integrated Strategic System Planning (Product ID 3002028534)

Guidelines for Linking Power Flow Analysis with Production Cost Modeling Tools for Integrated Strategic System Planning: Needs, Screening Methods, and Best Practices (Product ID 3002028535)

Wide-Area Distribution Assessments for Integrated Strategic System Planning (Product ID 3002028536)

## Other Reports:

- Current Modeling Capabilities and Practices for Integrated Planning: Review of Select Modeling Tools and Prominent Studies (Product ID 3002028537)
- A Distribution Perspective of Process, Capabilities, and Data for Integrated Planning (Product ID 3002028538)

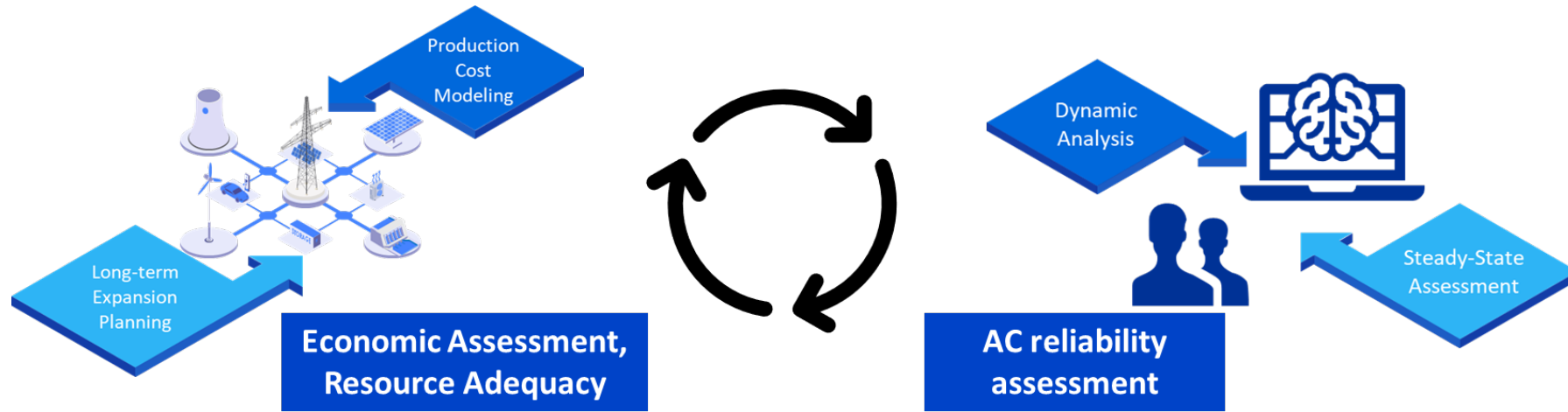
# Table of Contents

- 1 Introduction**  
Why Link Power Flow Analysis with Production Cost Simulation Studies?
- 2 Scenario Selection from PCM Data**  
Identifying Scenarios to Analyze
- 3 Mapping PCM Data to PF Cases**  
Steps to Map PCM Outputs to Power Flow Files
- 4 Conditioning Power Flow Cases**  
Methods to Achieve AC Feasibility
- 5 Summarizing the Process**  
Bringing it All Together



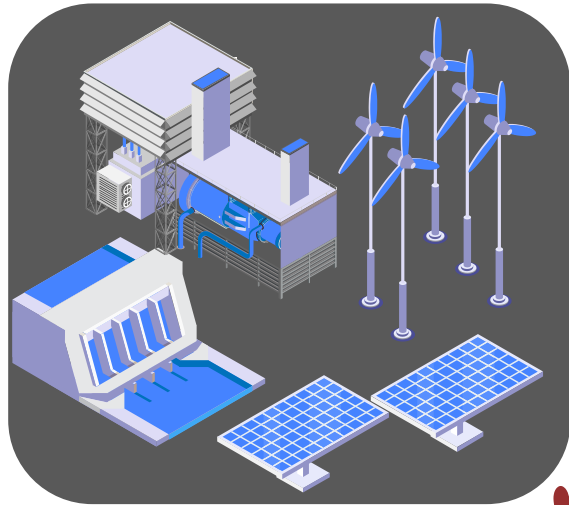
# 1 Introduction

# Linking Production Cost Models (PCMs) to Power Flow Analysis



- PCMs are operational studies that provide an assessment of future system operations and operating costs. These studies are a key part of the economic assessments made during a planning phase.
- PCM studies are however performed using a dc model (due to computational limitations), which approximates a real ac system. As such, an ac assessment is required to identify and resolve transmission system reliability concerns like thermal overloads, voltage stability issues that may exist in a system.
- Power flow (PF) studies are followed by dynamic studies that help transmission planners to ensure that the transmission system can operate stably for large and small disturbances.
- Traditional assessment uses a few peak, off peak, and shoulder loading cases which may not capture all the possible stressed operating conditions and the generation dispatch may not be reflective of the future conditions. Linking power flow analysis with PCM studies allows transmission planners to identify possible stress conditions by analyzing the entire 8760 load and dispatch and the created cases reflect the future load and generation better.
- In an integrated framework, it therefore becomes essential to be able to create ac power flow models from PCM studies so that the reliability of the system operational model can be studied in full details.
- The process of creating PF cases from PCM is also known as round trip and a topic of great interest among transmission planners.

# Key Challenges for Creating PF Models from PCMs



Outputs

Note: Only relevant output have been listed

- 8760 snapshots of:
- ✓ Nodal loads
  - ✓ Dispatch of conventional units
  - ✓ Dispatch of renewable generation
  - ✓ Dc line flows
  - ✓ Imports and exports on ties

Significant amount of data

*How does a transmission planner leverage this data for ac reliability assessment?*

*We identify 3 main challenges*

**Challenge 1:** Steady state and dynamic assessments of 8760 snapshots for a large power system is not realistic

**Solution:** Analyze the outputs from PCM studies and intelligently select a few representative snapshots for ac reliability assessment.

**Challenge 2:** For the selected scenarios ensuring that the PCM outputs are mapped to the power flow case properly is important

**Solution:** Develop a framework and automation scripts that allow transmission planners to map the values between different PCM and PF tools.

**Challenge 3:** A PCM solution is a dc solution. How do we make sure that the corresponding power flow case is ac feasible

**Solution:** Leverage best practices and guidance for case conditioning and reactive power management.

**Solving these challenges without automated processes can be significantly time consuming!!**



2

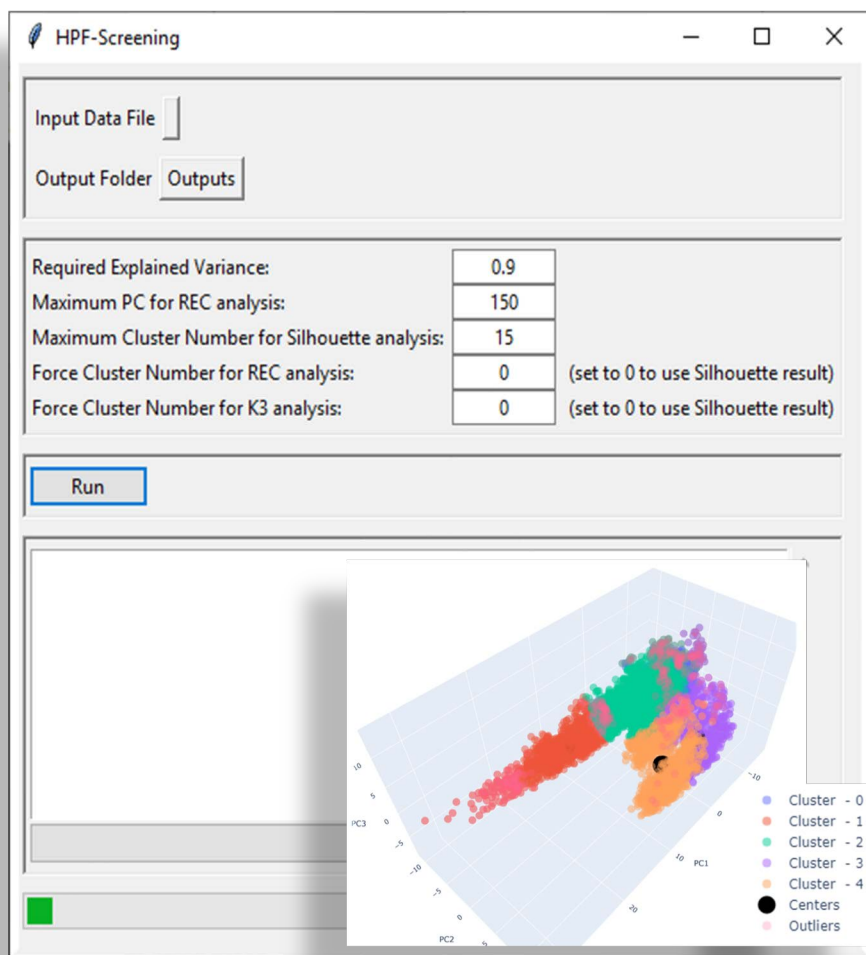
# Scenario Selection from PCM Data

# Selecting Scenarios from PCM Data

- Depending on system load levels, generation dispatch (both conventional and renewables) and system import/export conditions, some operating conditions can be exposed to reliability risks
- ***The aim of ac reliability assessment is to ensure that these reliability risks as well as reinforcements necessary to resolve these risks are identified*** via ac power flow and dynamic assessments
- Since 8760 ac assessments are not feasible for a large power system as this would be computationally burdensome, time consuming and unnecessary. Planners need to identify scenarios that are critical and perform ac reliability assessments on these reduced set of cases.
- ***With increased variability from loads as well as renewable generation, identifying critical operating conditions can be challenging.***
- An efficient way to perform this is ***to cluster hours into groups that have similar operating conditions (accounting for the variability)*** and then intelligently select representative hours from these groups.
- ***Principal component analysis (PCA) and clustering techniques provide a suitable way of handling multidimensional variability (e.g., variability in loads, generation, tie flows etc.) and grouping similar operating conditions .***

The EPRI HiLS tool automates the process of clustering operating hours

# High-Level Screening of Power Flows (HiLS)



HiLS V1.2 available on EPRI.com (PID: [3002024739](https://www.epri.com/3002024739))

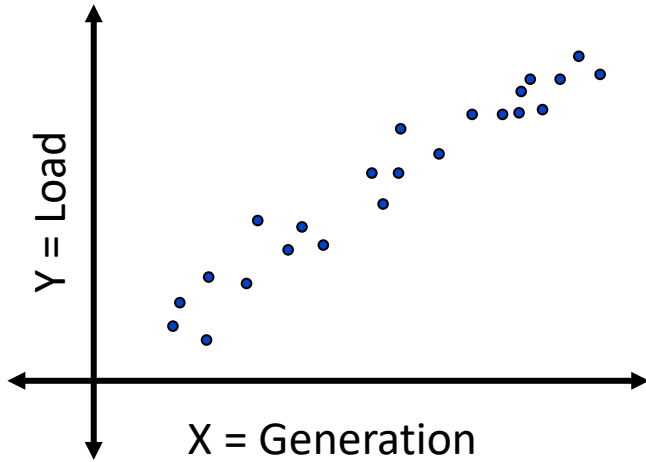
## Spectral Clustering using HiLS

Principal Component Analysis (PCA) identifies principal components (PC) from the input features that capture the variance in the dataset

Silhouette analysis identifies the optimal number of clusters required to produce compact clusters with maximum separation between clusters

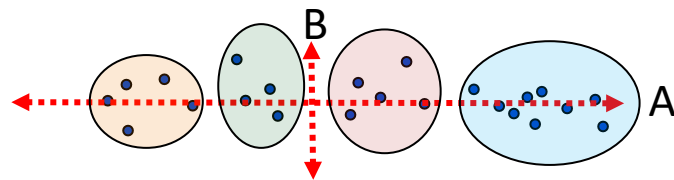
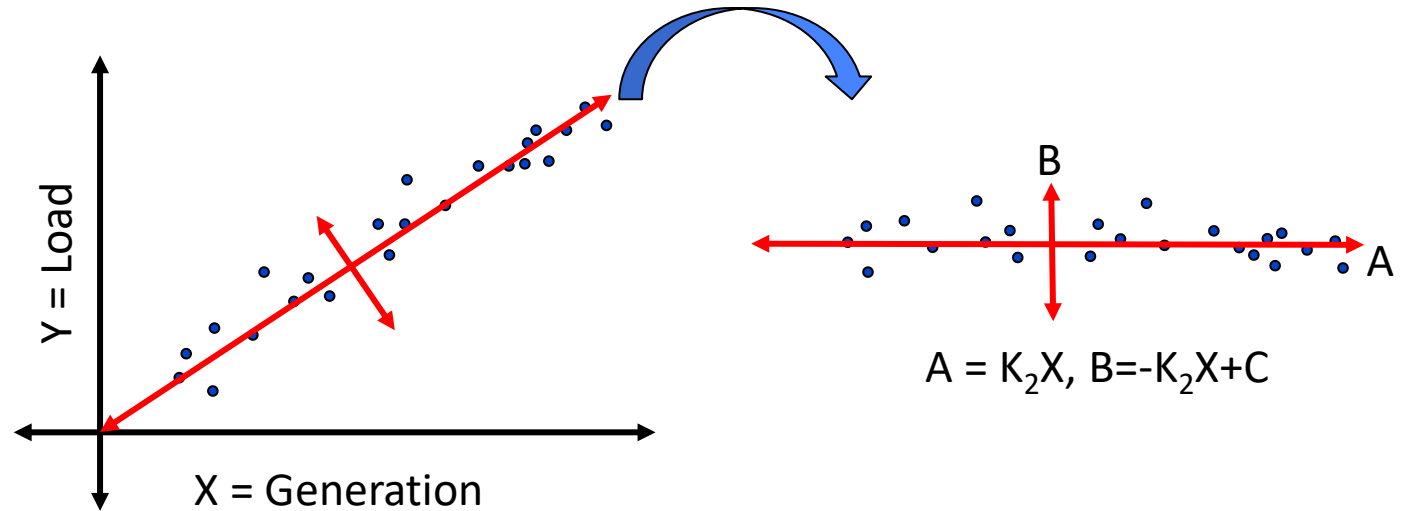
K-Means clustering using the identified PCs develops representative clusters

# PCA and Clustering Basics



*Principal component analysis (PCA) is a dimension reduction method used by data analysts. Given multidimensional data sets, **PCA allows analysts to translate the data into a lower dimensional space without diluting the variability in the data.** This can be explained by a simple example using 2-dimensional data for load and generation. From the plot one can see that the load and generation has positive correlation. As such, to look for variability, one can only the system at different generation levels, without analyzing the load separately, which means a high generation would mean high load. However, if this was multidimensional data, this assessment would be significantly tough. Let us examine how PCA can help.*

*PCA works by finding the two **red axes** shown in the plot **here**. This is done by using another mature linear algebra technique called **singular value decomposition**. The benefit of doing this is that now **any variability along the B – axis can be ignored and only studying the variability along the A axis would capture the impact of variability.** This reduces the dimension of the problem from 2 to 1.*



*The data can now be clustered around the **A-axis** using a suitable clustering method like **K-means** and a single operating point can be analyzed within each cluster as being representative of the conditions of the entire cluster. The single point can be chosen based on engineering judgement. **EPRI's High Level Screening (HiLS)** tool allows user to perform this type of data dimension reduction and clustering.*

Suggested Reading: <https://towardsdatascience.com/the-basics-principal-component-analysis-83c270f1a73c>

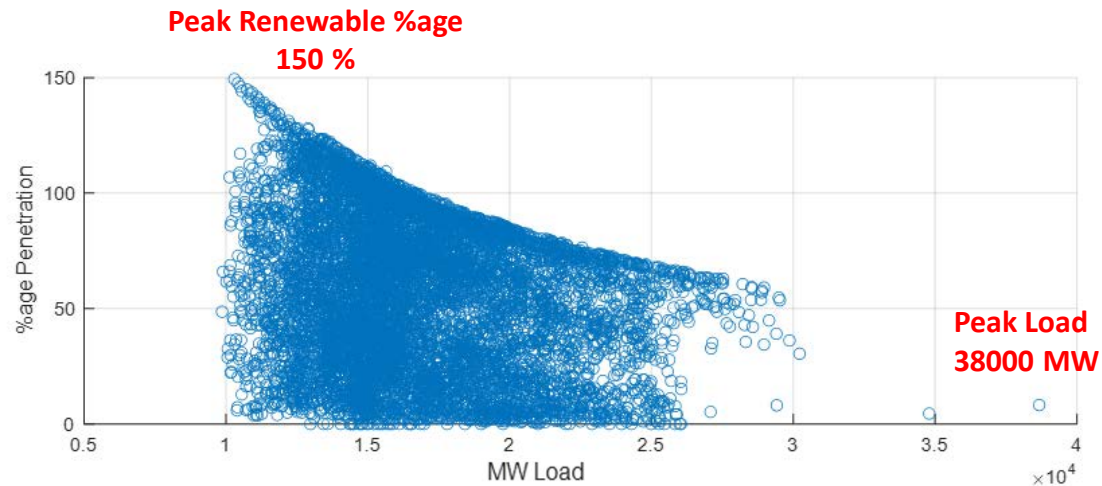
# Scenario Selection Example: The ISSP NY Case Study

- The data for scenario selection comes from the demonstration project for ***Integrated Strategic System Planning (ISSP)*** framework.
- The goal is to demonstrate a seamless analytical framework to assess future expansion plans across supply and delivery (T&D) that incorporates distributed resources and ensures reliability.
- ***Synthetic data created for the New York system*** was used to demonstrate the framework.
- As a part of transmission reliability assessment, ***the goal was to analyze the PCM data and select critical scenarios that would be further used for reliability assessment.***
- For the identified critical scenarios, ac power flow cases would be developed such that the loads and generation levels reflect the snapshot from the PCM.

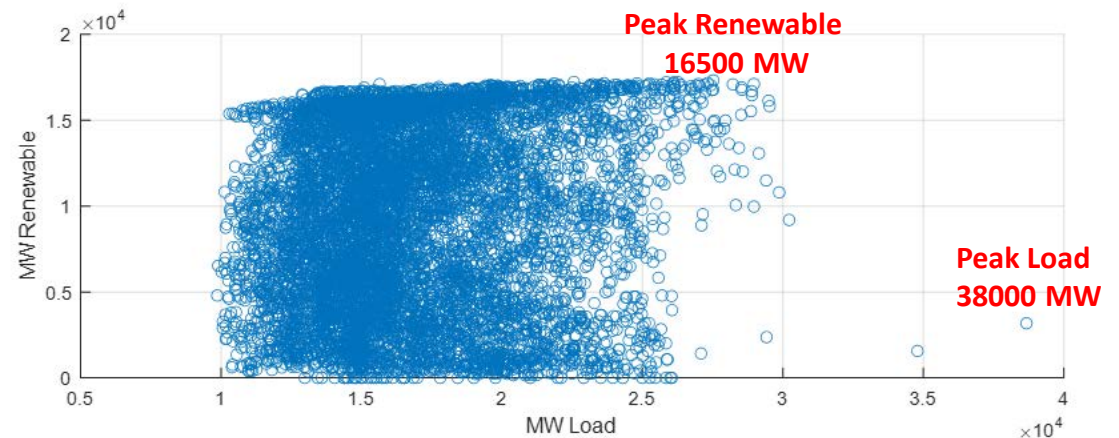
For more information: [www.epri.com/issp](http://www.epri.com/issp)

# System Information

- For the study it was assumed that the NY state was **implementing a decarbonization policy** which leads to a **significant increase in renewable generation from onshore and offshore wind** in 2035.
- The goal was to **screen scenarios that needs to be checked for ac transmission reliability** so that adequate **transmission reinforcements** can be built.
- The figures show that a variety of combinations of renewable generation (high and low) and system load (high and low) is possible for the future NY system.



**Percentage Renewables vs Load**



**MW Renewables vs. MW Load**

The high level of renewables can create unique combinations of system load and generation that will need to be examined for ensuring reliability

# PCM Data and HiLS Analysis

- For the PCA analysis, **14 different variables/quantities** from the PCM results were considered as input. The idea was to **create clusters with similar operating conditions considering the variability of these 14 different quantities over 8760 hrs.**
- To determine the number of clusters a **silhouette analysis[1]** was used. Based on the silhouette analysis, 5 clusters were developed
- This assessment was done using the **EPRI HiLS tool**

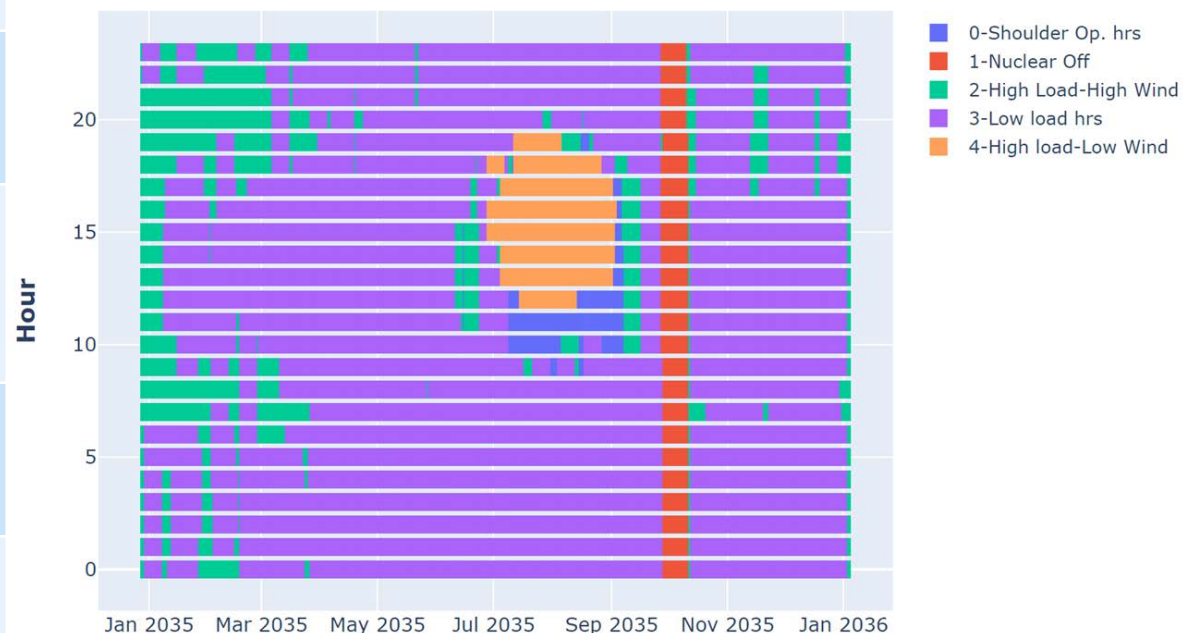
Variables/Quantities for PCA assessment	
Total Generation	Total Non-fossil Generation
Total Load	Total Fossil Fuel Generation
Total Wind Generation	Total Storage Output
Total Gas Based Generation	Total Power Export/Import
Total Diesel Generation	Power Export/Import to ISO-NE
Total Nuclear Generation	Power Export/Import to PJM
Total Coal Based Generation	Power Export/Import to Canada

[1] Suggested reading: [https://scikit-learn.org/stable/auto\\_examples/cluster/plot\\_kmeans\\_silhouette\\_analysis.html](https://scikit-learn.org/stable/auto_examples/cluster/plot_kmeans_silhouette_analysis.html)

# HiLS Assessment Summary

Cluster	Description	Expected Reliability Concerns	
		Steady state	Dynamics
0	Shoulder operating hours	Regional transmission issues	
1	Nuclear units out of service	Regional power transfer issues.	Low inertia, low SCR, frequency response adequacy
2	High load – High wind (Winter conditions)	Thermal overloads, voltage issues, Voltage collapse	Transient stability, Low SCR at wind plants
3	Low load operating hours	-	Low inertia, low SCR, frequency response adequacy
4	High load – Low wind (Summer conditions)	Thermal overloads, voltage issues, Voltage collapse	Transient stability, Delayed Voltage Recovery due to residential air-conditioning

## Hour-Cluster Membership Chart



- ❑ 5 clusters of hours covers the variability noted in the 14 different quantities examined from the PCM data.
- ❑ A single or few scenarios can be selected from each cluster for creating PF cases for ac reliability assessment.



3

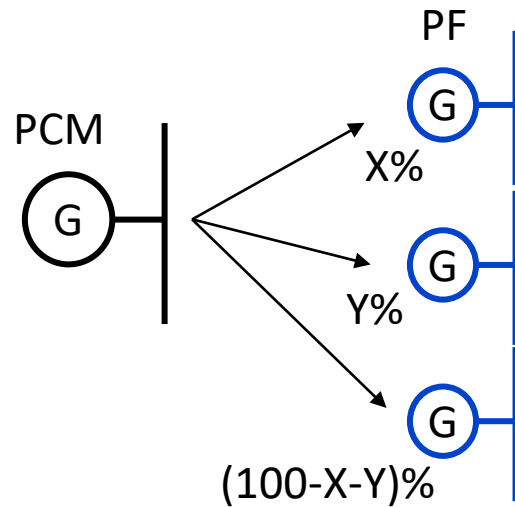
# Mapping PCM Data to PF Cases

# Background

- To create a PF case for a future planning year, TPs use a base power flow case of a near future year and add modifications to this case to reflect the changes for the future year.
- Mapping of PCM data/results to a PF model can be a challenging task
  - PCM tools may have a nodal level model which is not as detailed as a PF model. This means there will be a need for disaggregation of both loads as well as generators to a more granular level.
  - If not vetted properly, the network model between a PCM case and a power flow case can be different
- Both these challenges require ac reliability studies team to coordinate with their production cost study team.
  - An evaluation of similarities and difference between the two models is needed.
- ***The best practice would be to have identical topologies as well as identical bus level information in both power flow and PCM.***
  - PF models in general are more granular than PCM models
  - Some tools allow PCM models to have the exact network topology and bus information as a base PF models

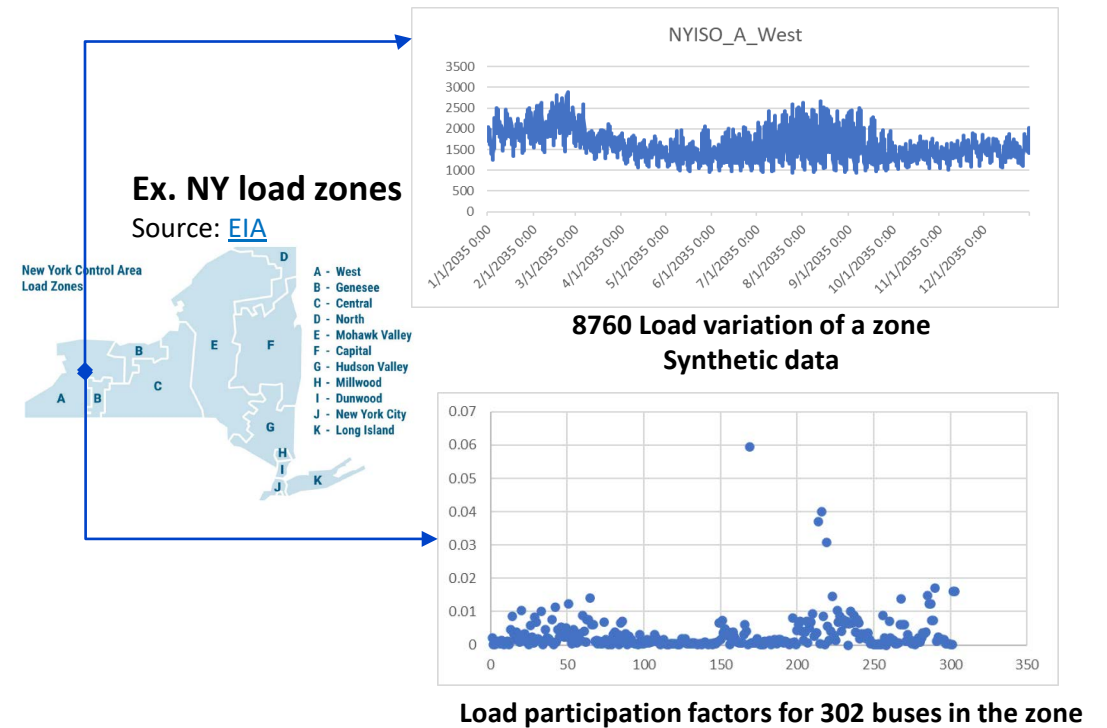
# Mapping of Loads and Generation

**Generators in PCM** can be modeled at a plant or even at a nodal level. These will need to be disaggregated for mapping to PF



- The **generation participation factors** (X, Y etc.) can either be available in the PCM or can be derived from the ratio of power output in available in the existing power flow case.
- New generators added as a part of a capacity expansion plan which appear in PCM may not exist in the PF case. These generators need to be identified and added to the PF case.

**Loads for PCM** studies are modeled at zonal level and load participation factors are available



- Loads at each bus can be calculated by multiplying the **load participation factor** to the total zonal load.
- Participation factors can be static (as shown here) or vary hourly

# Mapping of Loads and Generation

- **Different PCM tools can have very different output formats and hence mapping PCM to PF can be a challenging task requiring custom automation codes**
- A solution to this issue is to have a **common data format** in which the PCM data can be exported. For the ISSP work we created an intermediate data format in which the PCM data can be exported

Bus #	Generator	Gen ID	Area	Zone	Pgen
125024	Walden (GEN2)	2	NYISO	NYISO_G	0.309995
125093	West Coxsackie	1	NYISO	NYISO_G	0
125142	West Delaware Tunnel Plant	1	NYISO	NYISO_G	3.319423
125190	Proxy	P	NYISO	NYISO_G	2.893337
125192	LTnew_nggt-n_125192_ROSE GN2_24NY	1	NYISO	NYISO_G	0
125192	Proxy	P	NYISO	NYISO_G	2.875248
125193	Proxy	P	NYISO	NYISO_G	1.063937
125194	Proxy	P	NYISO	NYISO_G	0.650739
125201	Dashville (1)	1	NYISO	NYISO_G	2.390679

*Generator dispatch for a snapshot*

Bus #	Bus Name	Bus kV	Zone	Pload
100101	RUMFORD	115	ISONE_Maine	12.49287
100102	NORWAY	115	ISONE_Maine	19.68525
100104	LEWISTON LWR	115	ISONE_Maine	21.57444
100112	HARTLAND	115	ISONE_Maine	7.519118
100113	WYMAN HYDRO	115	ISONE_Maine	2.125846
100116	STURTEVANT	115	ISONE_Maine	13.08316
100117	LIVERMORE FL	115	ISONE_Maine	8.819367
100119	BROWNS CRSNG	115	ISONE_Maine	10.02549
100122	MAINE YANKEE	115	ISONE_Maine	4.684657

*Load data for a snapshot*

- **The output of a generation unit for a snapshot is based on generation participation factor and plant level dispatch**
- **The loads at each bus is based on the total zonal load and the load participation factor at the bus**

**Python based automation scripts were created as a part of the ISSP work to extract the information from the PLEXOS PCM tool and then map it to PSS®E**



4

# Conditioning Power Flow Cases

# Background

- Conditioning a PF case after it has been mapped can be a challenging task.
- PCM dispatches are based on dc assessment and do not provide information on reactive power setpoints of generators or shunt devices on the network
- If certain voltage levels are not monitored in PCM (e.g., sub-transmission system, generator step up transformer etc.) extreme thermal as well as voltage violations may show up in the power flow case.
  - May need adding infrastructure or upgrading transformers in the PF case
- If a portion of a large interconnection is being studied (e.g., NYISO system as a part of the eastern interconnection), it must be ensured that the tie line flows in the PF are adjusted to reflect the conditions in the PCM snapshot.
  - May require adding fictitious generators or loads across tie lines to ensure that tie flows are within a certain threshold

# Conditioning Power Flow Cases

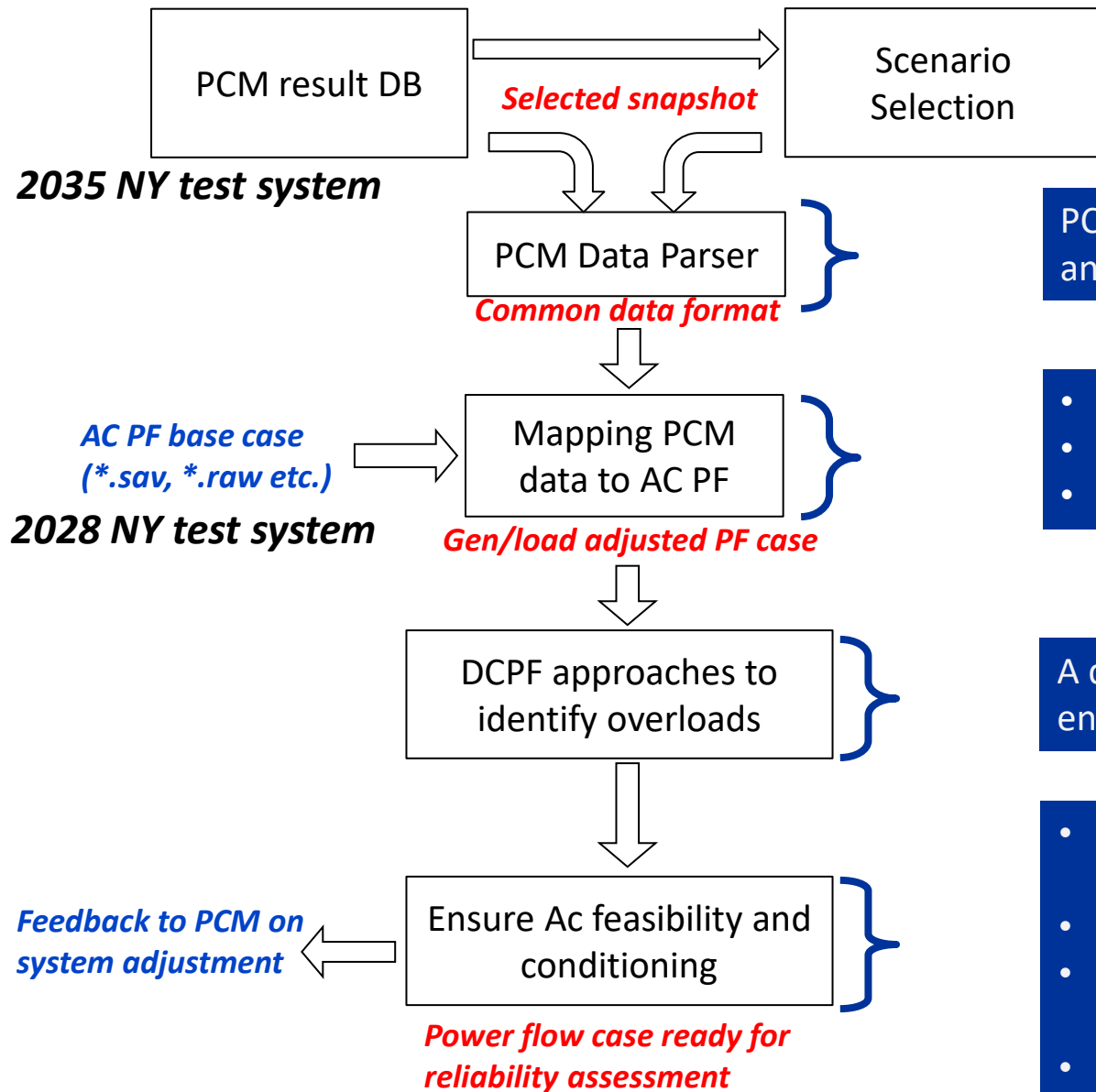
- Use ***dc power flow to identify initial overloads*** in the system. New lines may be needed to make the initial case ac feasible
- ***Do not disconnect de-committed generators.*** Keep them at 0 MW but let them supply vars. This helps to manage reactive power in the system
  - Disconnect these generators incrementally after a well-conditioned case is obtained
- ***De-energize lines that fall below their surge impedance loading (SIL).*** This is typically an issues if generation in some areas have been de-committed
  - These lines can inject significant charging current and can overload lines.
- An ***optimal power flow based, or sensitivity-based method*** can be used to ***adjust the reactive power set points of both online generators as well as switched shunts*** to ensure monitored voltages are within normal operating limits
- A conditioned case should have all line flows below or at rated limit and voltages withing the normal range.
- ***Importantly, perform an N-1 assessment for all HV transmission lines and above and ensure that the N-1 cases do not diverge. This step ensures conditioning.***
- ***A reference that discusses these approaches in detail:*** [Automated Tool to Create Chronological AC Power Flow Cases for Large Interconnected Systems](#) (B. Vyakaranam et. al.)



5

# Summarizing the Process

# Creating Power Flow Cases for Selected PCM Snapshots



*Summary of the process adopted for the ISSP demonstration project*

PCM data parsed to a common format, so that it can be mapped to any power flow case

- Plant level generation data may need to be disaggregated
- Nodal level load data needs to be disaggregated to load buses
- Net load needs to be disaggregated to gross load and DER

A dc power flow is used to add the minimum set of lines needed to ensure that power flow has an initial solution

- Add or adjust generation/load to ensure tie flows are met within reasonable limits
- Identify transmission path additions to ensure N-0 sufficiency
- Identify shunt compensation and voltage set points to ensure acceptable voltage levels
- Review and change taps throughout to ensure voltages are proper

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A blue-tinted photograph of four diverse professionals standing together. From left to right: a woman with curly hair and glasses wearing a white lab coat; a man with glasses and a tie wearing a white lab coat; a woman wearing a white hard hat and a dark polo shirt; and a man with glasses and a beard wearing a light-colored button-down shirt. They are all looking towards the camera with slight smiles.

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