Microgrid Modeling Needs: Safety and Dynamic Interaction of Distributed Energy Resources

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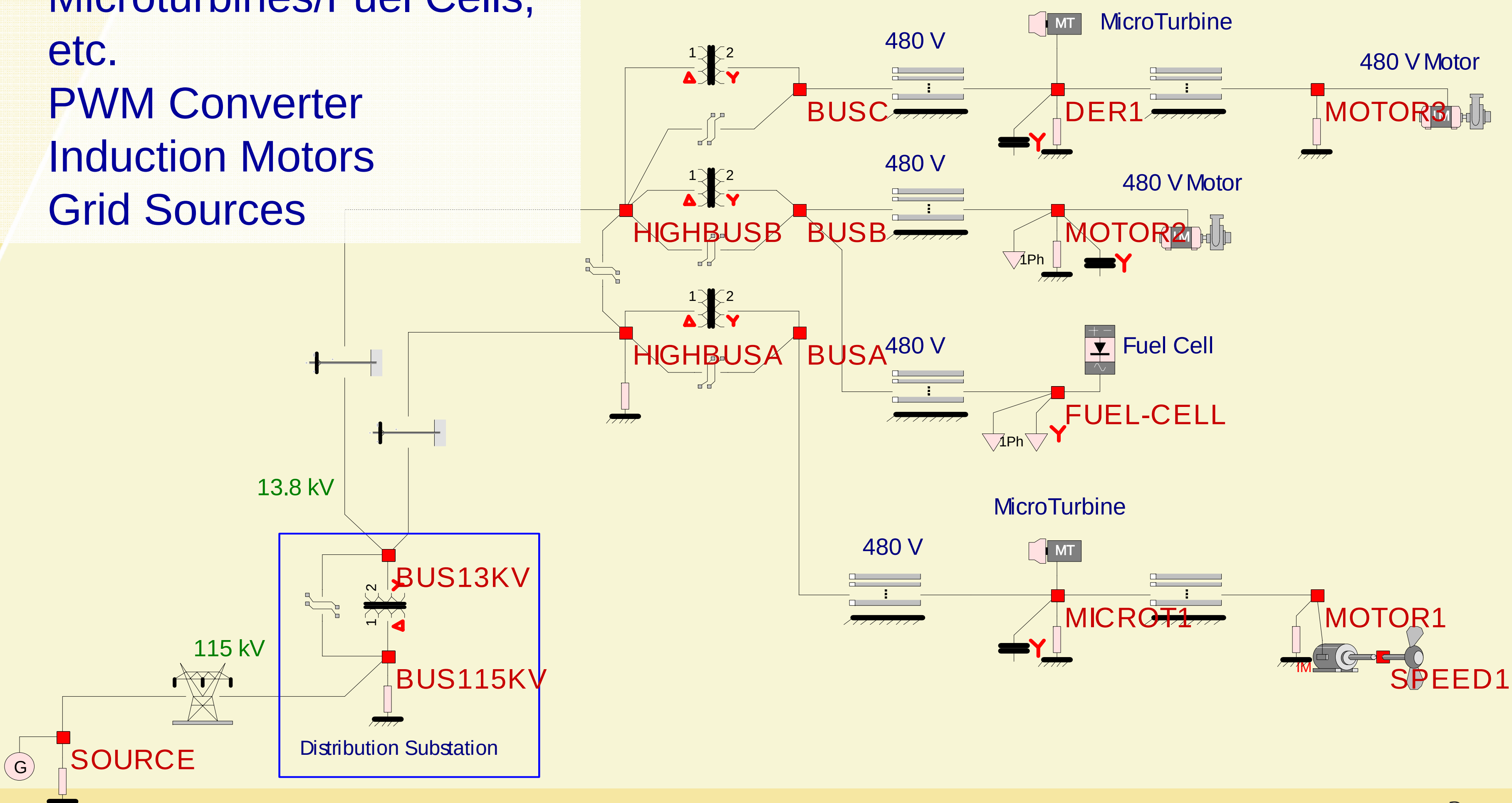
Outline

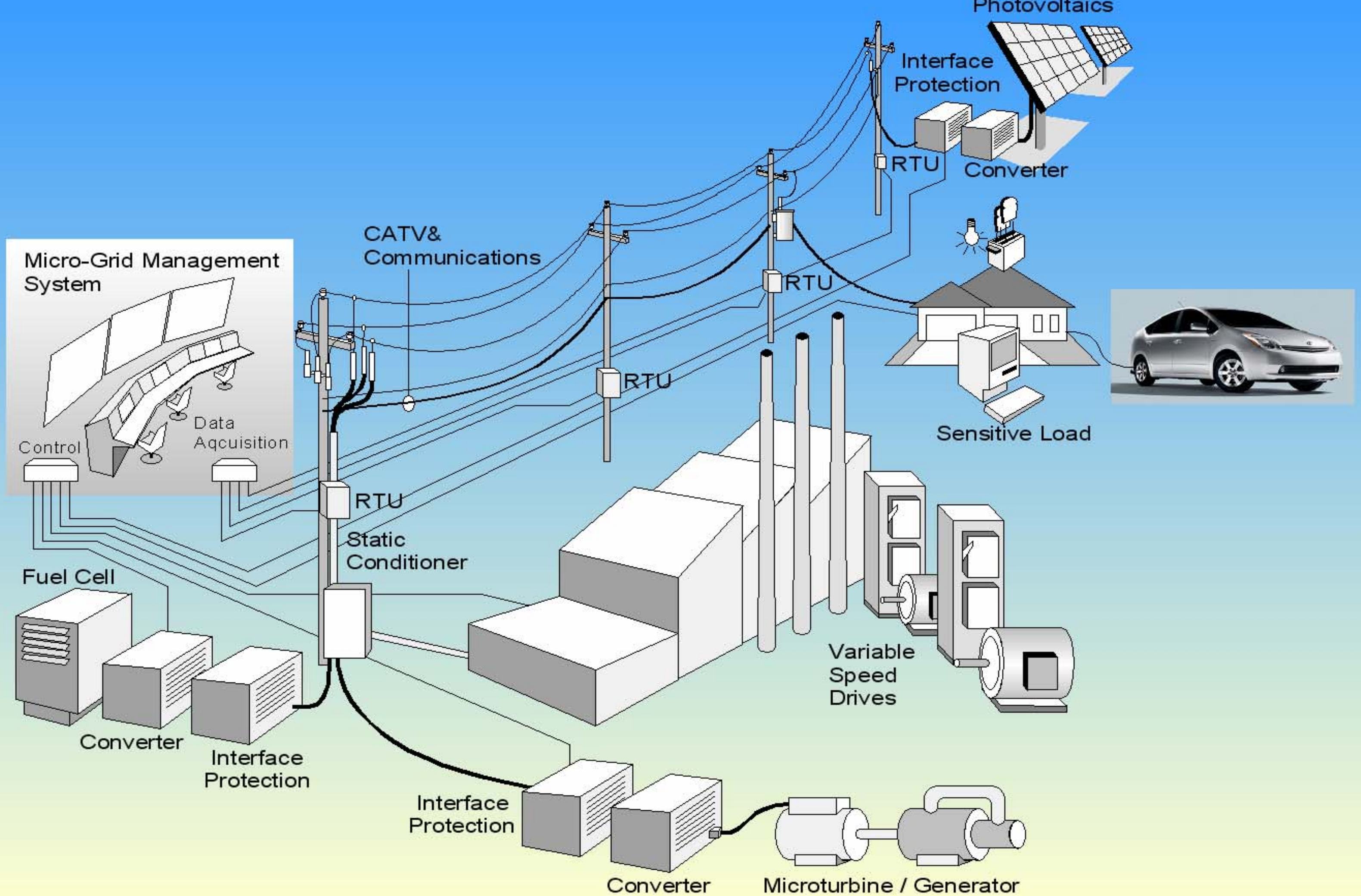
- Distributed Energy Systems - μGrids
- Desirable Analytical Capability
- Modeling Methodology
- Safety Assessment – Stray Voltages
- Small Signal Stability Analysis
- Example Case Study
- Conclusions

µGrids: Typical Configuration

- Power Lines
- Transformers
- Microturbines/Fuel Cells, etc.
- PWM Converter
- Induction Motors
- Grid Sources



The DER Concept for Utilities



Distributed Energy Resource Technologies

- Wind – Double Fed Induction Generators
- Photovoltaic
- Fuel Cells
- Microturbines
- Plug-In Hybrid Cars
- Storage: Batteries, Flywheels, Magnetic, etc.

Common Technical Characteristics

- Power Electronic Interface
- Inertialess
- Current Limited

Challenge and Opportunity

μGrid Analysis Tool
Desirable Characteristics

- Analysis Tool for DER Integrated Systems That Captures all Physical Phenomena.
- The distribution system may contain three-wire, four-wire and five-wire circuits.
- The μGrid may supply three phase as well as single phase loads.
- The μGrid source (DERs) interface is via Inertialess Converters.
- The μGrid sources may operate under different control laws. As a matter of fact, control functions are expected to increase as manufacturers become more sophisticated.
- A multiplicity of alternate operational philosophies.
- Interaction of Controls, Rating/Derating, Voltage Support at PCC, GenLoad-Frequency Control, Safety, etc.
- **Dynamic Interactions - Stability**

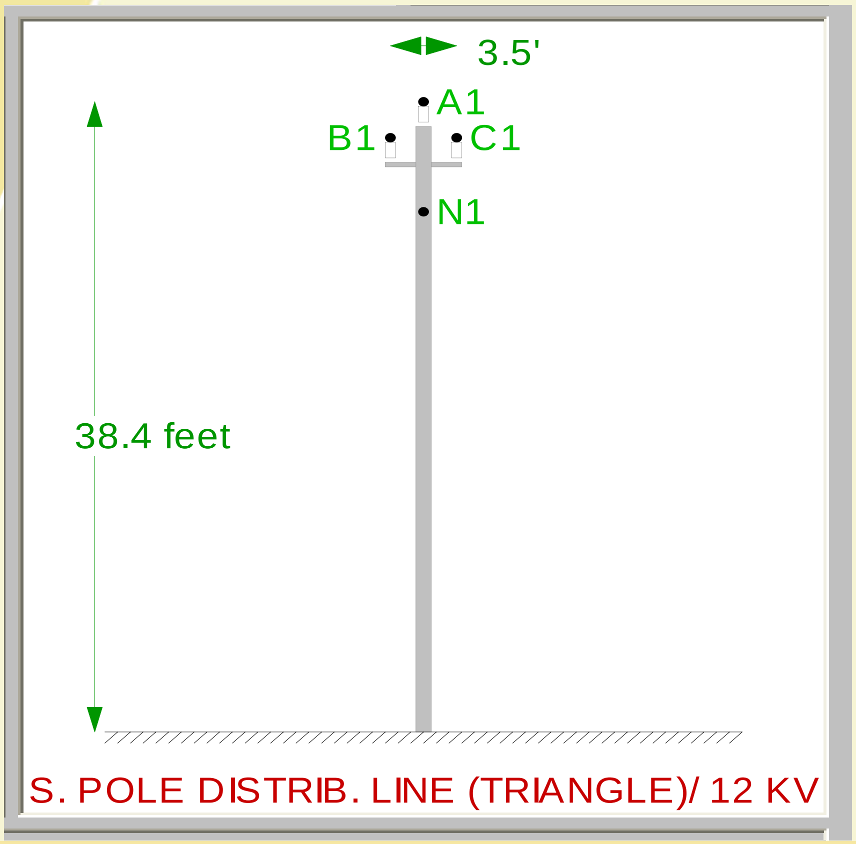
µGRD: Unique Characteristics

- Components are modeled in direct phase quantities without any approximating assumptions, for example symmetrical components.
  - Provides the capability of handling three wire, four-wire and five-wire systems
  - Provides high fidelity models
  - Provides voltages and currents in Neutral wires and ground wires

Direct Modeling: Physically Based Models

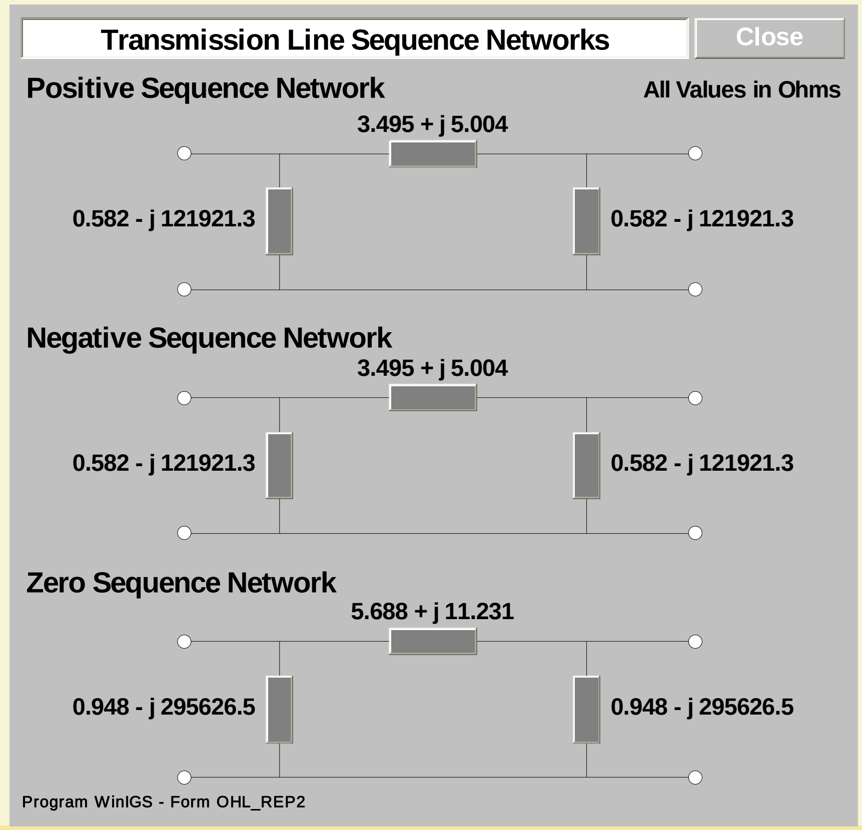
Example: Three Phase Power Line

Physically Based Model

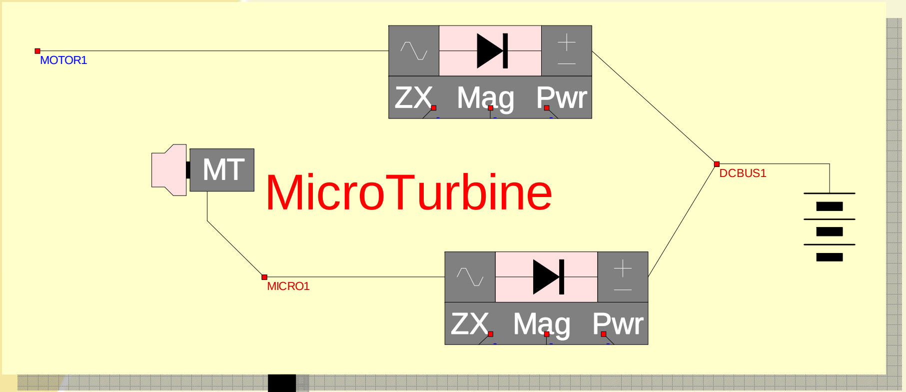


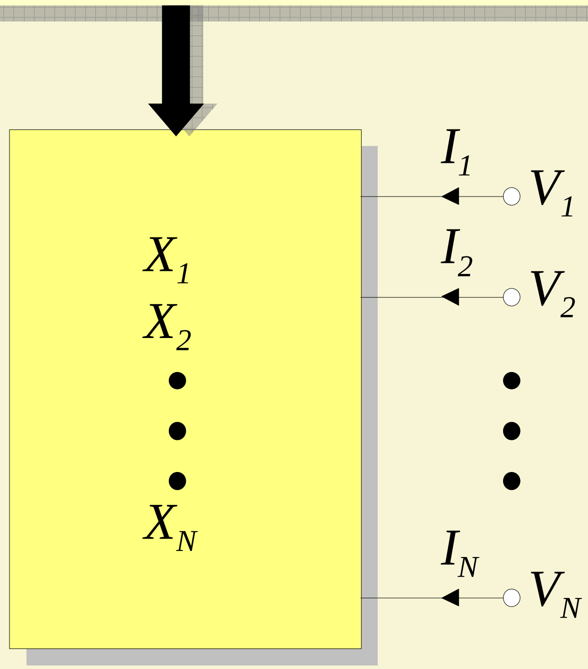
Sequence Parameter Model

IT IS NOT USED



Quadratized Component Model





$$\begin{bmatrix} i^k \\ 0 \end{bmatrix} = Y^k x^k + \begin{bmatrix} {x^k}^T F_1^k x^k \\ {x^k}^T F_2^k x \\ \vdots \end{bmatrix} - b^k$$

Where: $$x^k = \begin{bmatrix} v^k \\ v^k \end{bmatrix}$$

The model captures any possible control options

No Simplifying Assumptions

Steady State Analysis

Component Model

$$\begin{bmatrix} I_r^k \\ I_i^k \\ 0 \end{bmatrix} = y_{eq\_real}^k x^k + \begin{bmatrix} x^{kT} f_{eq\_real1}^k x^k \\ x^{kT} f_{eq\_real2}^k x \\ \vdots \end{bmatrix} - b_{eq\_real}^k$$

Where

$$x^k = \begin{bmatrix} V_r^k \\ V_i^k \\ y^k \end{bmatrix}$$

Connectivity Equations

System Model

$$G(x) = Y_{real}\, x + \begin{bmatrix} x^T f_1 x \\ x^T f_2 x \\ \vdots \end{bmatrix} - B_{real} = 0$$

PSERC

Steady State Analysis

Component Model

$$\begin{bmatrix} I_r^k \\ I_i^k \\ 0 \end{bmatrix} = y_e^k \ldots \begin{bmatrix} x^{kT} f_{eq\_real1}^k x^k \\ \vdots \end{bmatrix}$$

Where

Solution - Newton's Method

$$x^{\nu+1} = x^{\nu} - J_G^{-1}\left\{ Y_{real}\, x^{\nu} + \begin{bmatrix} x^{\nu T} f_1 x^{\nu} \\ x^{\nu T} f_2 x^{\nu} \\ \vdots \end{bmatrix} - B_{real} \right\}$$

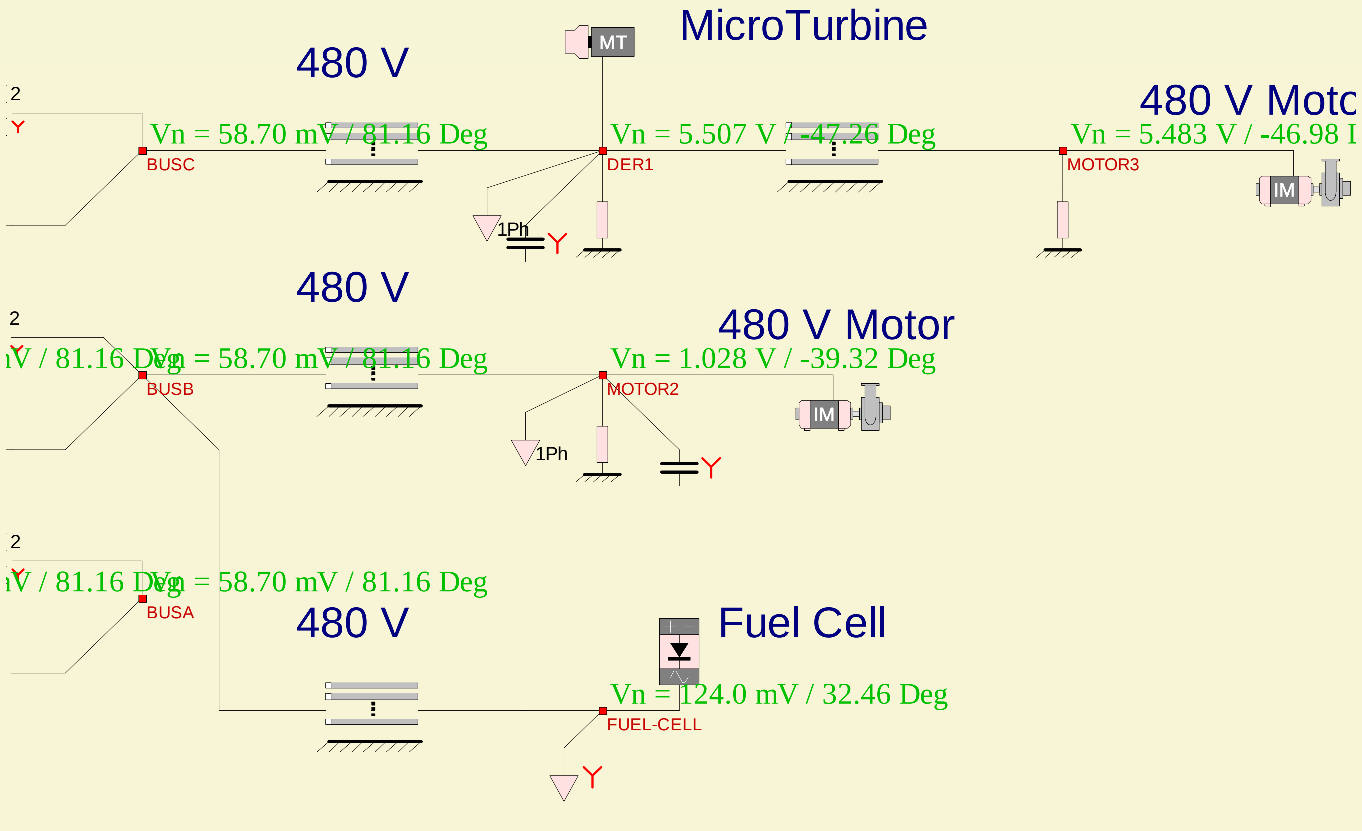
$$G(x) = Y_{real}\, x + \begin{bmatrix} \vdots \\ x^T f_2 x \\ \vdots \end{bmatrix} - B_{real} = 0$$

µGRD Safety and Grounding

Exposure Factor:
More Folks Near a µGrid versus an Electrical Installation

Safety Issues

- Touch Voltages
- Stray Voltages (Example)
- GPR
- Faults (in µGrid and Utility)

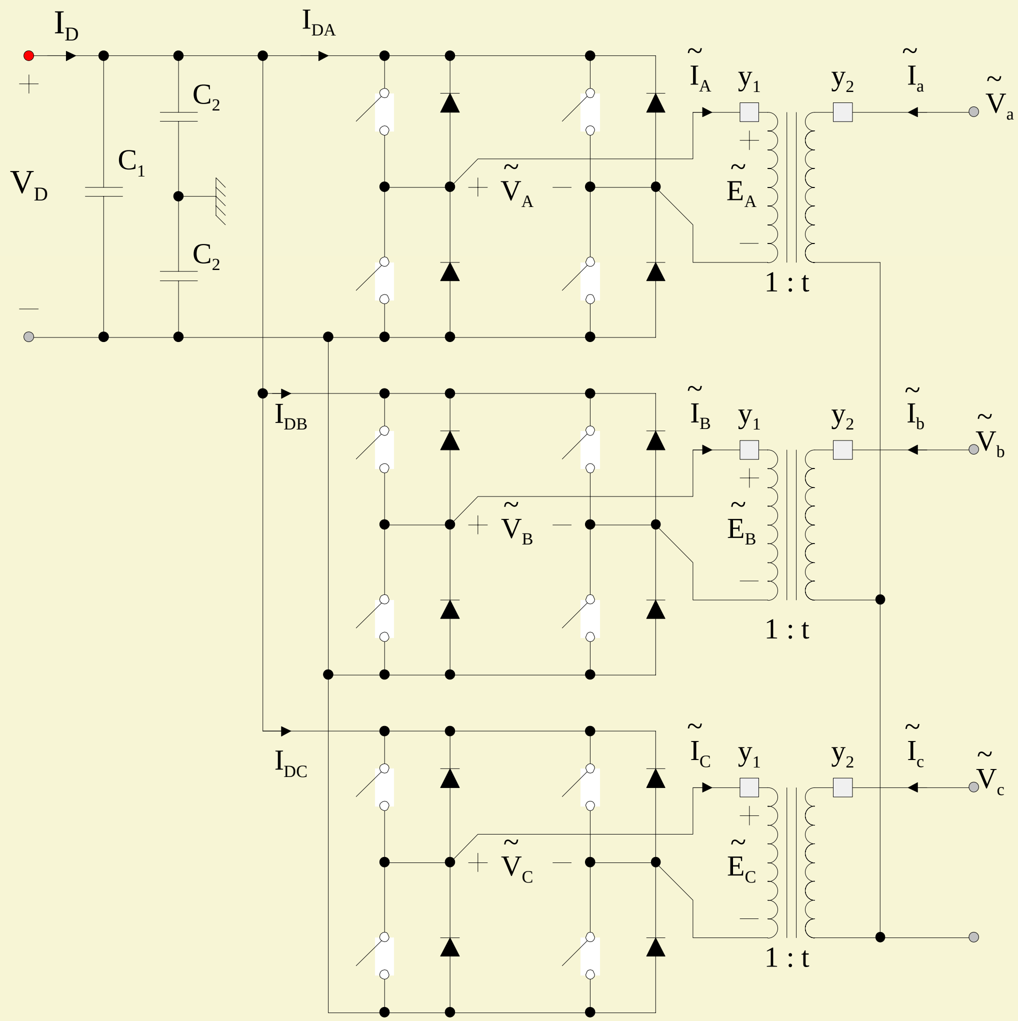


Interactions:
Steady State, Dynamic, Stability

- DER Systems Have Their Own Controls
- DER Controls Interact Under Steady State Conditions (μGrid Model)
- Multiple DERs on Same Circuit May Interact Dynamically
- New approach: Object Oriented Small Signal Stability

Microturbine-Utility Interface

Generic DC-AC Converter with Segregated Phases



DC-AC Converter - Steady State Model

Interface Equations

$$\begin{cases} \tilde{I}_a = y_2\left(\tilde{V}_a - t\tilde{E}_A\right) \\ \tilde{I}_b = y_2\left(\tilde{V}_b - t\tilde{E}_B\right) \\ \tilde{I}_c = y_2\left(\tilde{V}_c - t\tilde{E}_C\right) \\ I_d = I_A + I_B + I_C \end{cases}$$

Power Balance

$$\begin{cases} 0 = I_A^2 - y_1 y_1^*\left(\tilde{V}_A - \tilde{E}_A\right)\left(\tilde{V}_A - \tilde{E}_A\right)^* \\ 0 = I_B^2 - y_1 y_1^*\left(\tilde{V}_B - \tilde{E}_B\right)\left(\tilde{V}_B - \tilde{E}_B\right)^* \\ 0 = I_C^2 - y_1 y_1^*\left(\tilde{V}_C - \tilde{E}_C\right)\left(\tilde{V}_C - \tilde{E}_C\right)^* \end{cases}$$

Phase Control

$$\begin{cases} 0 = \tilde{V}_A - d\tilde{m}_a\left(x_1 + jx_2\right)V_d \\ 0 = \tilde{V}_B - d\tilde{a}^2\tilde{m}_a\left(x_1 + jx_2\right)V_d \\ 0 = \tilde{V}_C - d\tilde{a}\tilde{m}_a\left(x_1 + jx_2\right)V_d \\ 0 = x_1^2 + x_2^2 - 1.0 \end{cases}$$

Transformer

$$\begin{cases} 0 = y_2 t\left(\tilde{V}_a - t\tilde{E}_A\right) - y_1\left(\tilde{V}_A - \tilde{E}_A\right) \\ 0 = y_2 t\left(\tilde{V}_b - t\tilde{E}_B\right) - y_1\left(\tilde{V}_B - \tilde{E}_B\right) \\ 0 = y_2 t\left(\tilde{V}_c - t\tilde{E}_C\right) - y_1\left(\tilde{V}_C - \tilde{E}_C\right) \end{cases}$$

DC Power

$$0 = V_d I_d - P_{specified}$$

Small Signal Stability - Eigenvalue Analysis

$$\frac{dx(t)}{dt} = Ax(t) \quad \leftrightarrow \quad x(t+h) = \Phi x(t)$$

$$\lambda_d \quad \leftrightarrow \quad e^{\lambda_a h}$$

λ_a *physical system eigenvalue – matrix A*

λ_d *discrete system eigenvalue – matrix* Φ

Small Signal Stability for μGrids
DERs Interfaced with Converters

PSERC

Approach A:

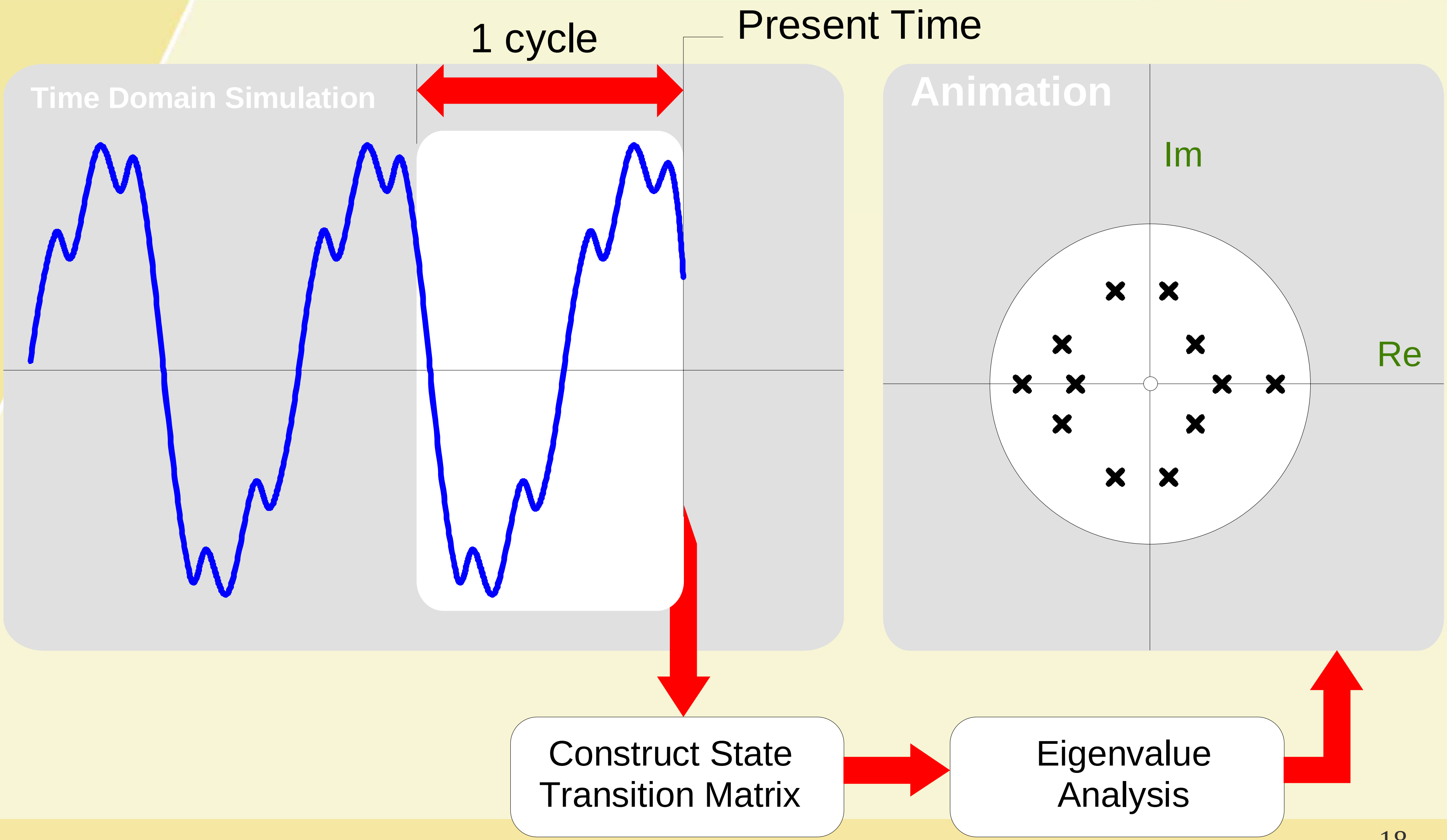
Compute Transition Matrix,
Compute Eigenvalues of Transition Matrix

Approach B:

Derive Aggregate Quadratic Model,
Compute Steady State Solution
Linearize Model Around Solution
Compute Eigenvalues of Linearized Model

Validation: Compare Results

Small Signal Stability Analysis Approach B



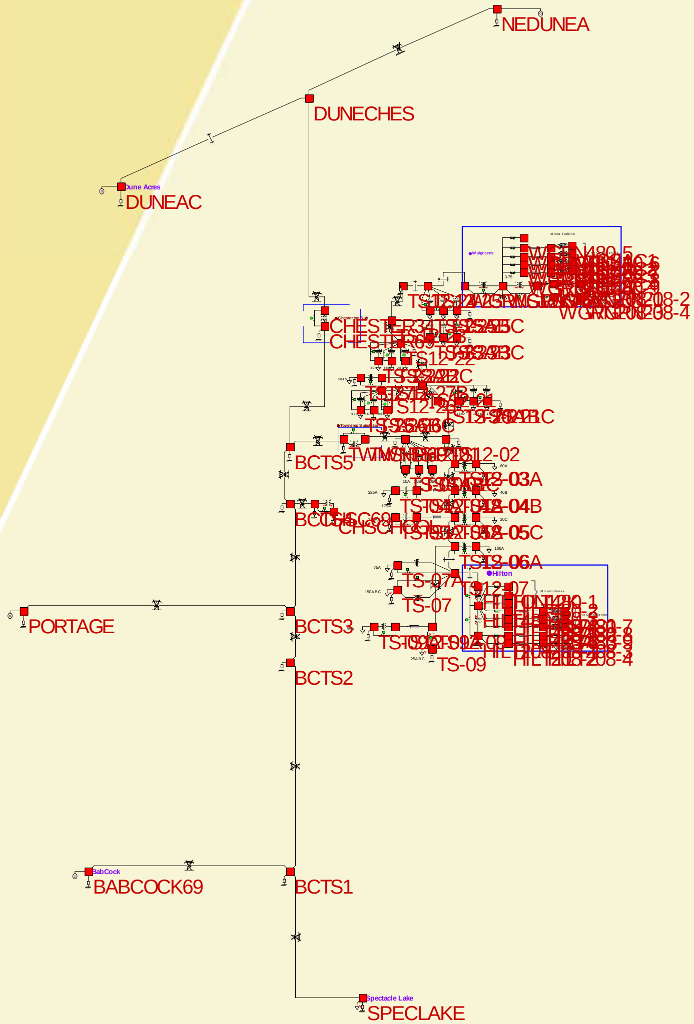
Approach B

- Construct the Transition Matrix for Each Device
- Combine Device Transition Matrices into Network Transition Matrix
- Extract Eigenvalues of Network Transition Matrix

Stability Analysis Case Study
Case Description

Distribution System in Chesterton, Indiana

Distribution System in Chesterton, Indiana



Model Includes:

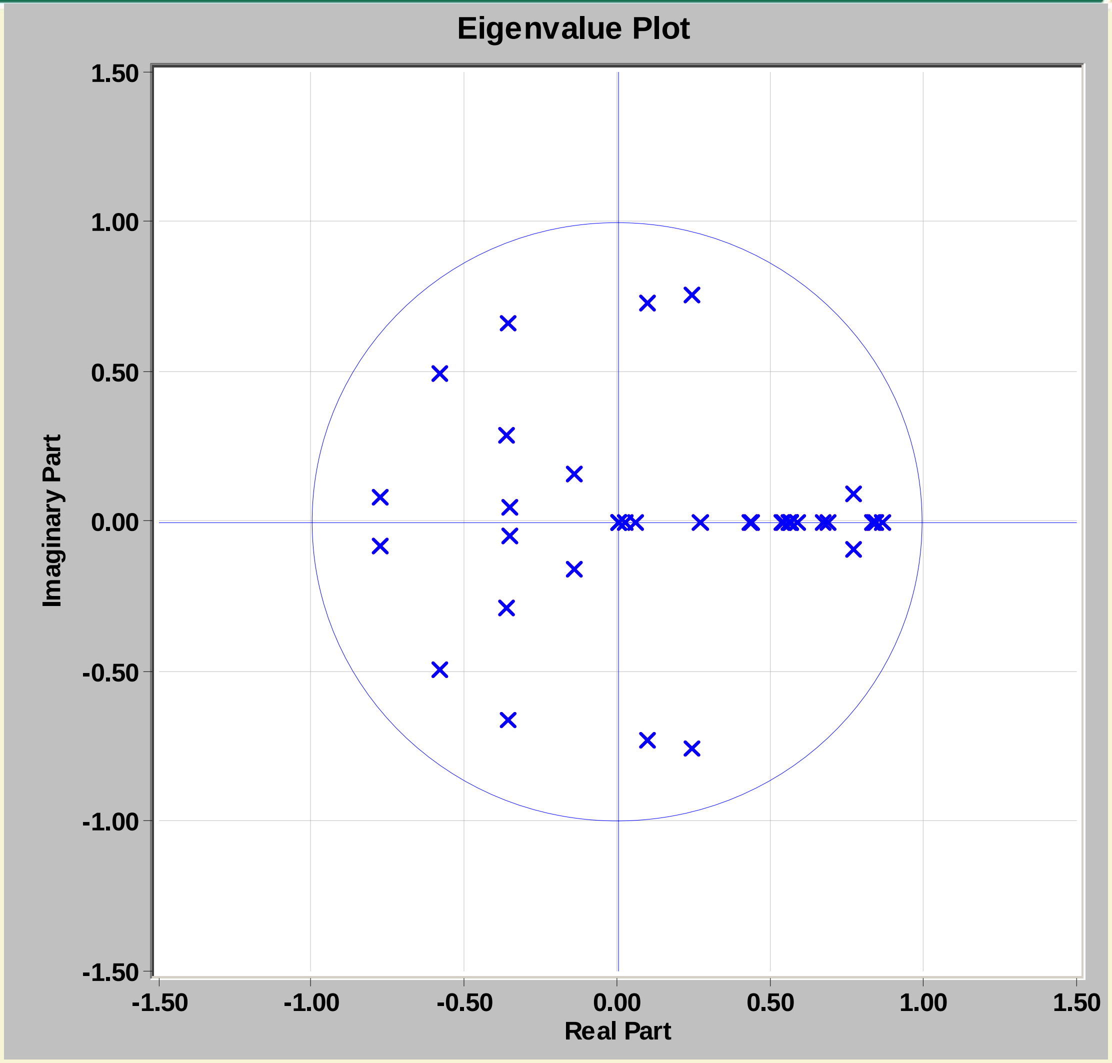
- 12 kV Distribution System
- Four Distribution Substations
- 34 and 69 kV Transmission Lines Terminating at Substations
- Distribution Transformers and Major Loads
- Four Microturbine DER's

Stability Analysis Case Study
Case Descriptions

DER's / Case #	DER#1	DER#2	DER#3	DER#4
Base Case	OFF	OFF	OFF	OFF
1	OFF	**ON**	OFF	OFF
2	**ON**	**ON**	OFF	OFF
3	OFF	**ON**	**ON**	OFF
4	**ON**	**ON**	**ON**	OFF
5	**ON**	**ON**	**ON**	**ON**
6	OFF	**ON**	**ON**	**ON**

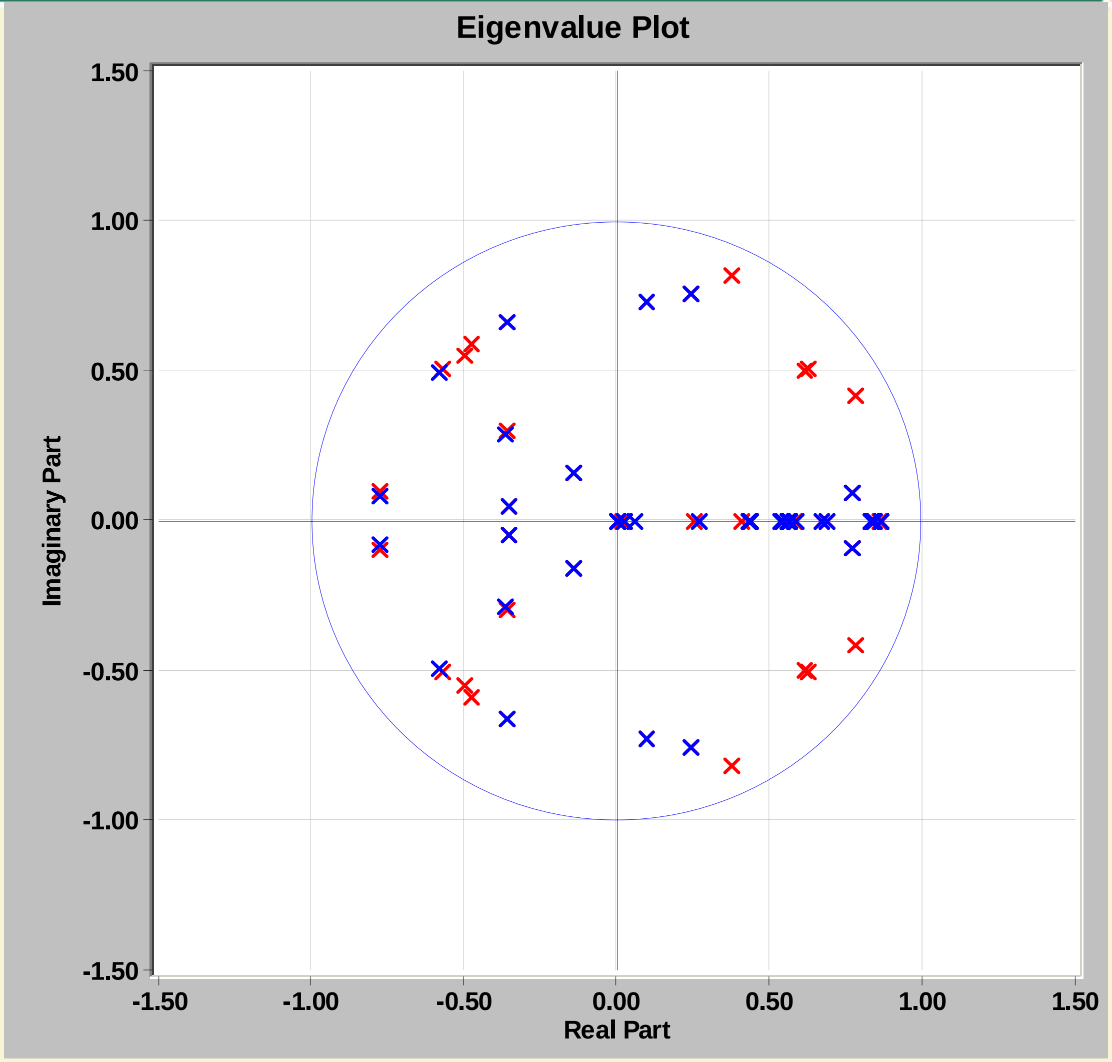
Stability Analysis Case Study

Base Case – Discrete System Eigenvalues



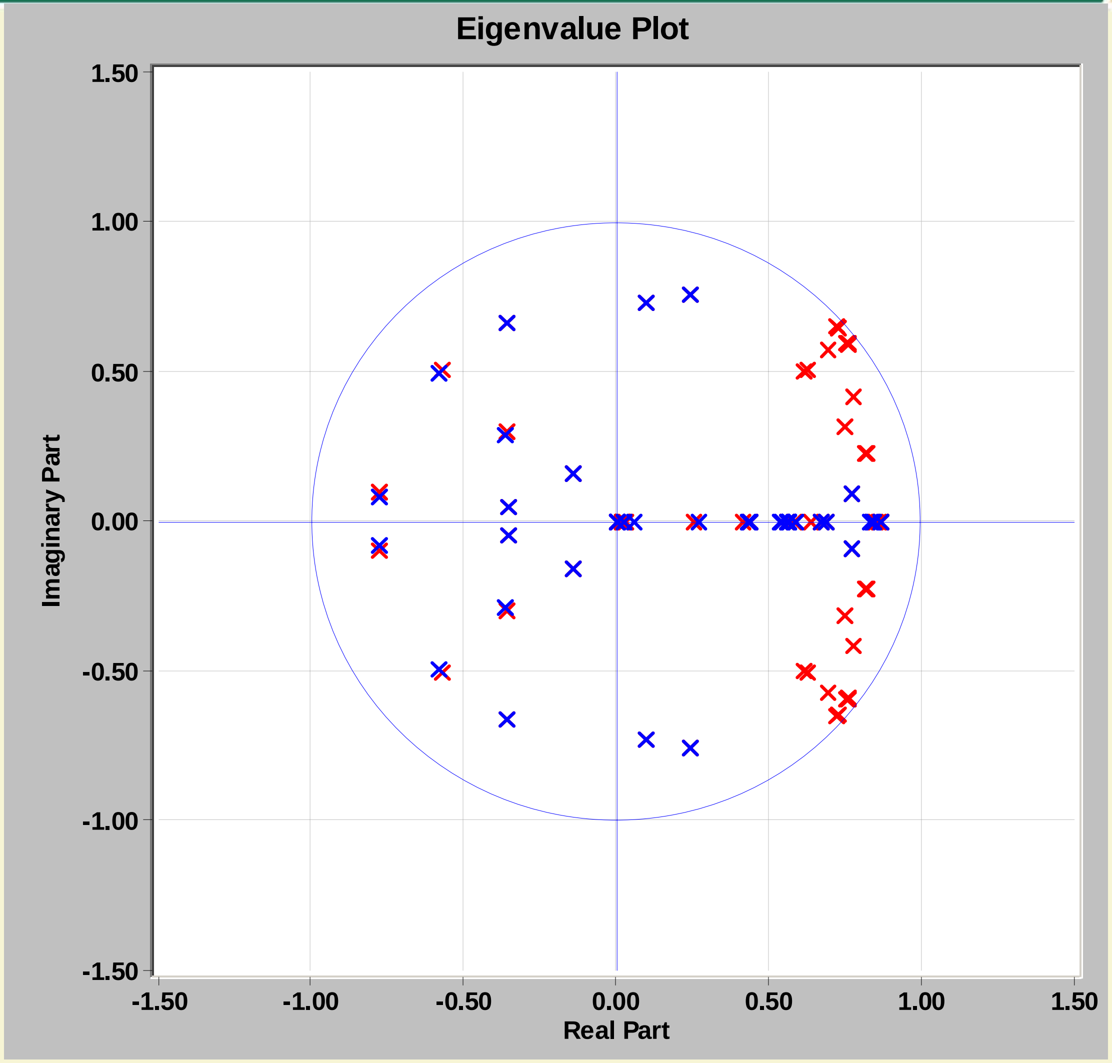
Stability Analysis Case Study

Case 2 – 2 DER'S ON – Discrete System Eigenvalues



Stability Analysis Case Study

Case 5 – 4 DER'S ON – Discrete System Eigenvalues



Conclusions

- Understanding the dynamic interactions of μGrids will lead to better designs of interfaces between the utility and the distributed energy resources.
- The feasibility of constructing an integrated model of the utility system and DER installations without any approximations was demonstrated. This model is useful in studying (a) safety issues, (b) protection issues and (c) the interaction of DERs with the utility system.
- The stability characterization of the integrated utility/distributed energy resources system exhibits dynamic interactions between utility/distributed energy resources as well as among distributed energy resources.
- The controls of the DER interface converter play a very important role in these dynamic interactions.
- Converter design and controls are usually proprietary. Cooperation with manufacturers to construct proper interface converters models will facilitate improved designs.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