Evaluation of Islanding Detection Methods for PV Utility-interactive Power Systems

By

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Methods for Detecting an Island?

Introduction

- **Rationale for Anti-Islanding Requirements**
- **Standards and Code Activities**
- **Overview of Anti-Islanding Detection Methods:**
- **Rationale for Test Methods**
- **Test Methods and Standards**

Introduction

- Active and Passive Descriptions
- Strengths & Weaknesses of Methods
- Non-detection Zone (NDZ) Descriptions
- Testing Methods
- Summary

Rationale for Anti-islanding Detection

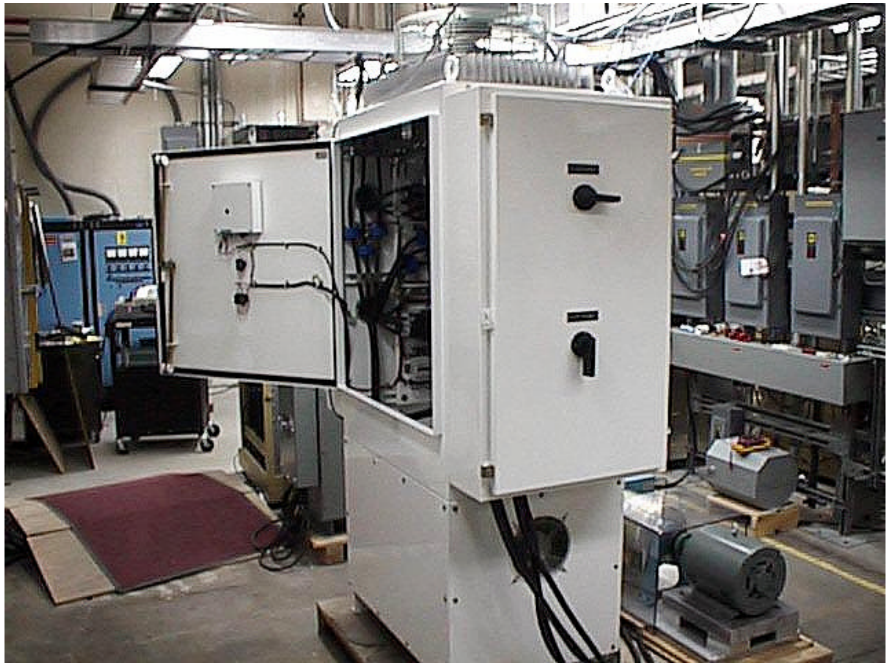
Rationale for Anti-islanding Requirements

- 1. The Utility Cannot Control Voltage and Frequency in the Island, Creating the Possibility of Damage to Customer Equipment in a Situation Over Which the Utility Has No Control.
- 2. Utilities, Along With the PV Distributed Resource Owner, Can Be Found Liable for Electrical Damage to Customer Equipment Connected to Their Lines That Results From Voltage or Frequency Excursions Outside of the Acceptable Ranges.

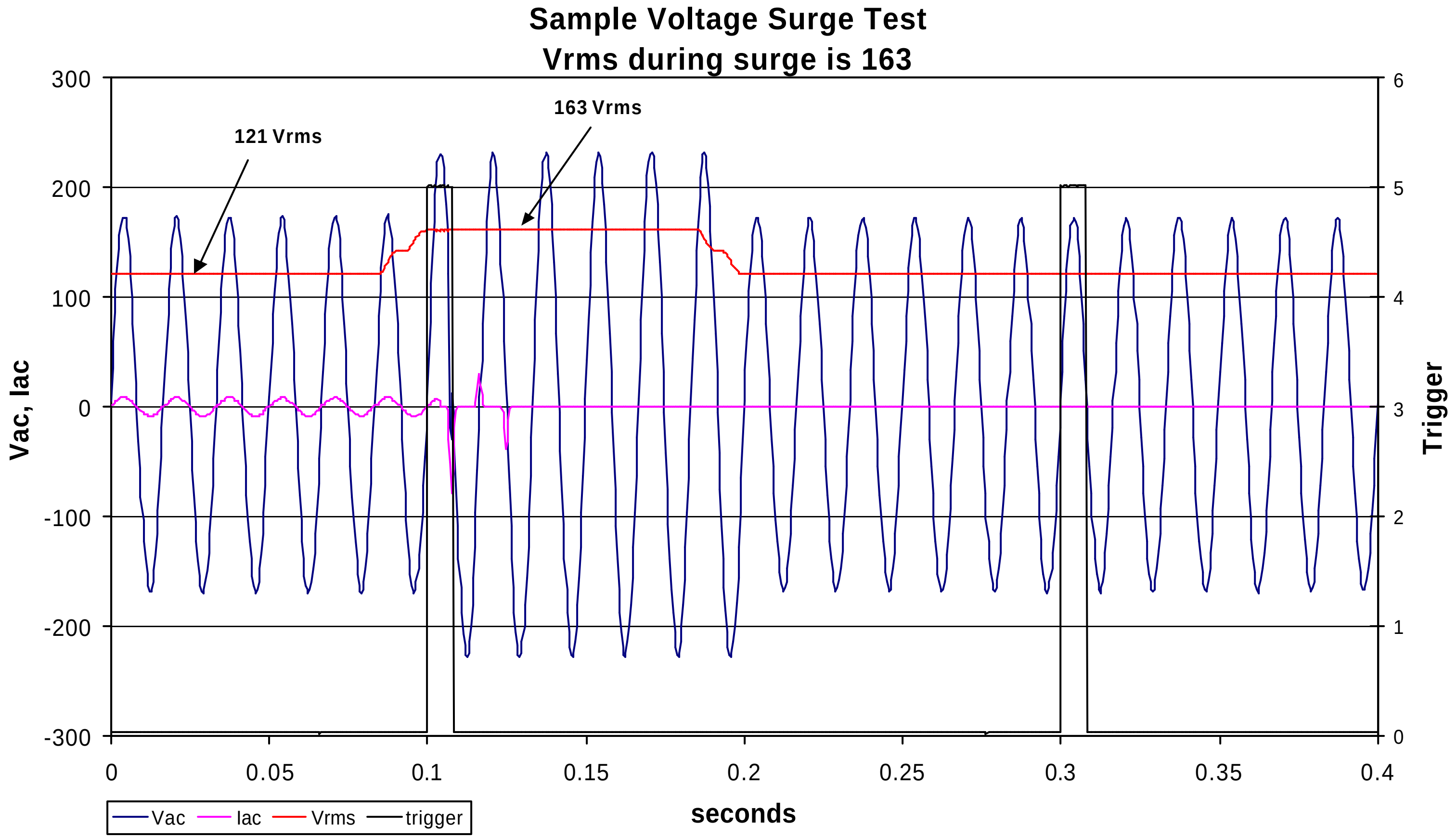
Rationale for Anti-islanding Requirements

- 3. Islanding May Create a Hazard for Utility Line-workers by Causing a Line to Remain Energized That May Be Assumed to Be Disconnected From All Energy Sources.
- 4. Reclosing Into an Island May Result in Re-tripping the Line or Damaging the Distributed Resource Equipment, or Other Connected Equipment, Because of Out-of-phase Closure.
- 5. Islanding May Interfere With the Manual or Automatic Restoration of Normal Service by the Utility.

PV Inverters Must Not Island When Connected to the Utility



Anti-Islanding in Action



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Methods for Detection of Islanding

- Passive Inverter Resident
- Active Inverter Resident
- Active Non-resident (Utility)
- Passive Non-resident (Utility Control)

Passive Methods Resident in the Inverter

- **Under/over Voltage and Under/over Frequency**
- **Voltage Phase Jump Detection**
- **Detection of Voltage Harmonics and Detection of Harmonics**

Active Methods Resident in the Inverter

- Impedance Measurement
- Detection of Impedance at Specific Frequency
- Detection of Voltage Harmonics and Detection of Harmonics
- Slip Mode Frequency Shift
- Frequency Bias

Active Methods Resident in the Inverter

- **Sandia Frequency Shift**
- **Sandia Voltage Shift**
- **Frequency Jump**
- **Mains Monitoring Units with Allocated All-pole Switching Devices Connected in Series (MSD). Also (ENS).**

Methods at the Utility Level

- Impedance Insertion (Active)
- Protection Relaying (Passive)

Methods Using Communications Between the Utility and PV System

- **Power Line Carrier Communications**
- **Signal Produced by Disconnect**
- **Supervisory Control and Data Acquisition (SCADA)**

Rationale for Anti-island Test Methods

- **Verify Anti-island Detection Works**
  - **Tests Must be Low Cost**
  - **Number of Inverters Tested Minimized**
  - **Anti-Island For Multiple Inverters Must be Verified**
  - **Tests Must be Repeatable**
    - **Noise Levels and Test Circuit Specified**
    - **Utility, Simulated Utility Impedance Specified**

Multiple-inverter Tests

- **Tests Must Consider Active Anti-island Synchronization**
- **Tests Must Consider Utility Impedance Values**
- **Noise May be Required!**

Standards and Codes Activities

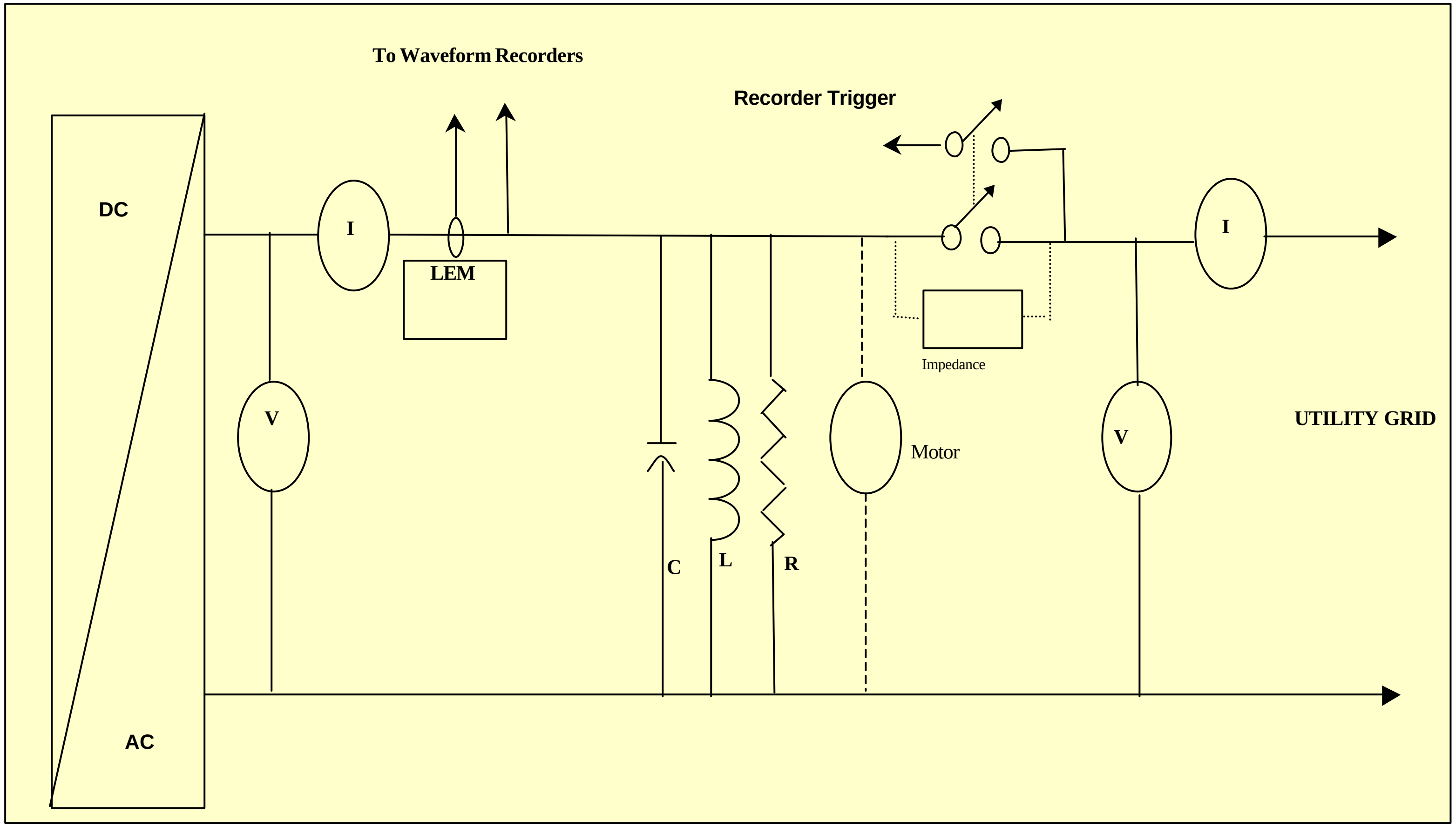
- **Photovoltaic Interconnect Standards and Requirements are Being Written. Standards Organizations Include:**
  - **IEC**
  - **IEEE**
  - **Underwriters Laboratories**
- **IEA PVPS Member Countries**

USA (IEEE 929-2000) and (UL1741) Standards Methods

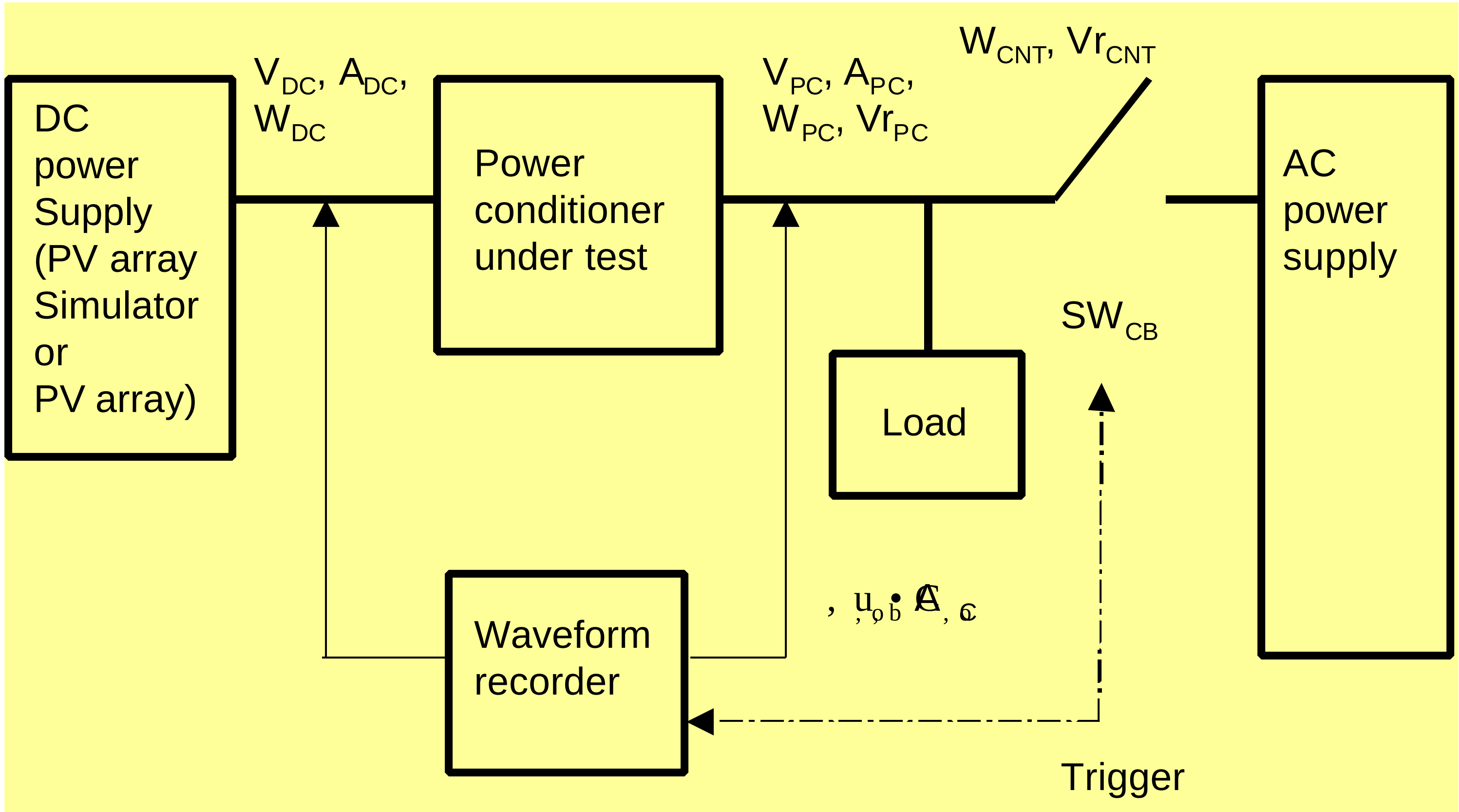
- **Test Procedures to Verify Islanding Detection Works.**
  - Required for
  - Interconnection

- **Requirements for Anti-islanding and Interconnection Are Spelled Out**

Anti-Island Test Circuit (929/1741)

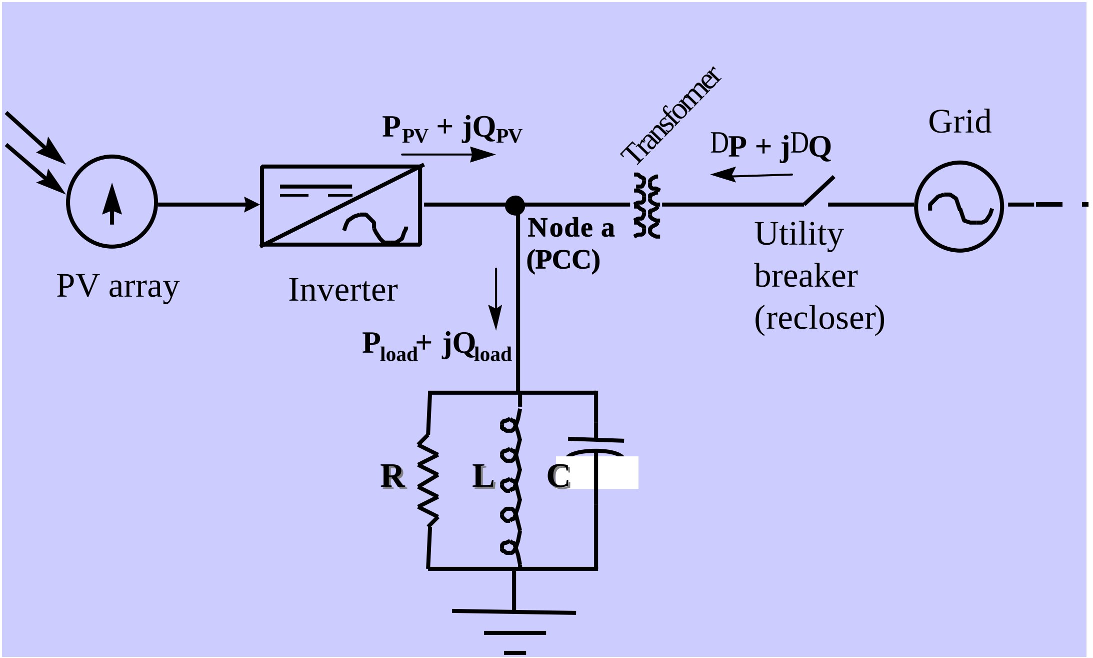


Draft International Standard
IEC 62116



End Of Part 1

Definitions of System Configuration, Power Flows and Terms



PV System/Utility Feeder Configuration Showing Definitions of Power Flows and Terms.

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Passive Inverter Resident

Under/over Voltage and Under/over Frequency

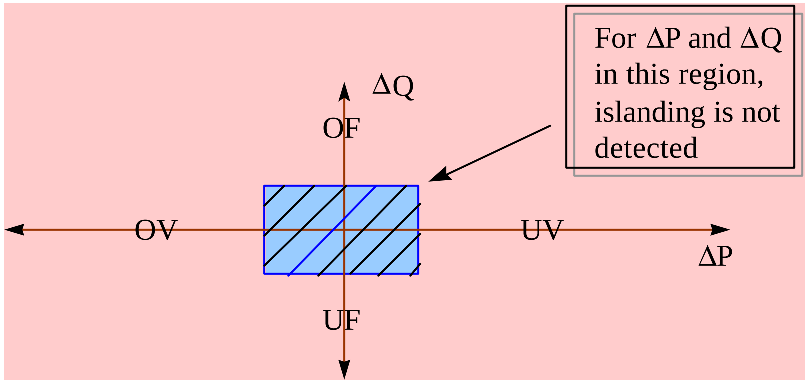
Description

- Inverter operation is only allowed within a selected amplitude/frequency window.
- If the amplitude or frequency of the PCC voltage leaves the window, the PV system is disconnected from the utility.

Under/over Voltage and Under/over Frequency

- **Also** ***Standard Protective Relays; Abnormal Voltage Detection***
  - **Strengths: Low Cost, Equivalent to Utility Protection, Is Used in Conjunction with Other Anti-islanding Methods**
  - **Weaknesses: Large NDZ, Slow Reaction Times**
  - **NDZ: Dependent on Impedances, Power Ratings, Operating Point**

U/O Voltage & U/O Frequency NDZ Description



Mapping of the NDZ within the Power Mismatch Space (? P versus ? Q for Over/under Voltage and Over/under Frequency.

- **NDZ Includes All L and C Allowing Conditions to Fall Within the Crosshatched Area**

Voltage Phase Jump Detection

- **Also** ***Power Factor Detection; Transient Phase Detection***
  - **Description: Monitor the Phase Difference Between the Inverter and the Utility for a Sudden Jump**
  - **Strengths: Easy to Implement, Does not Affect the Output Power Quality or System Transient Response**
  - **Weaknesses: Difficult to Choose Thresholds that Detect Islanding without False Trips**
  - **NDZ: Unity Power Factor Loads Produce No Phase Error. If Inverter is Not Unity Power Factor Then It Must Be Bidirectional.**

Phase Jump Detection

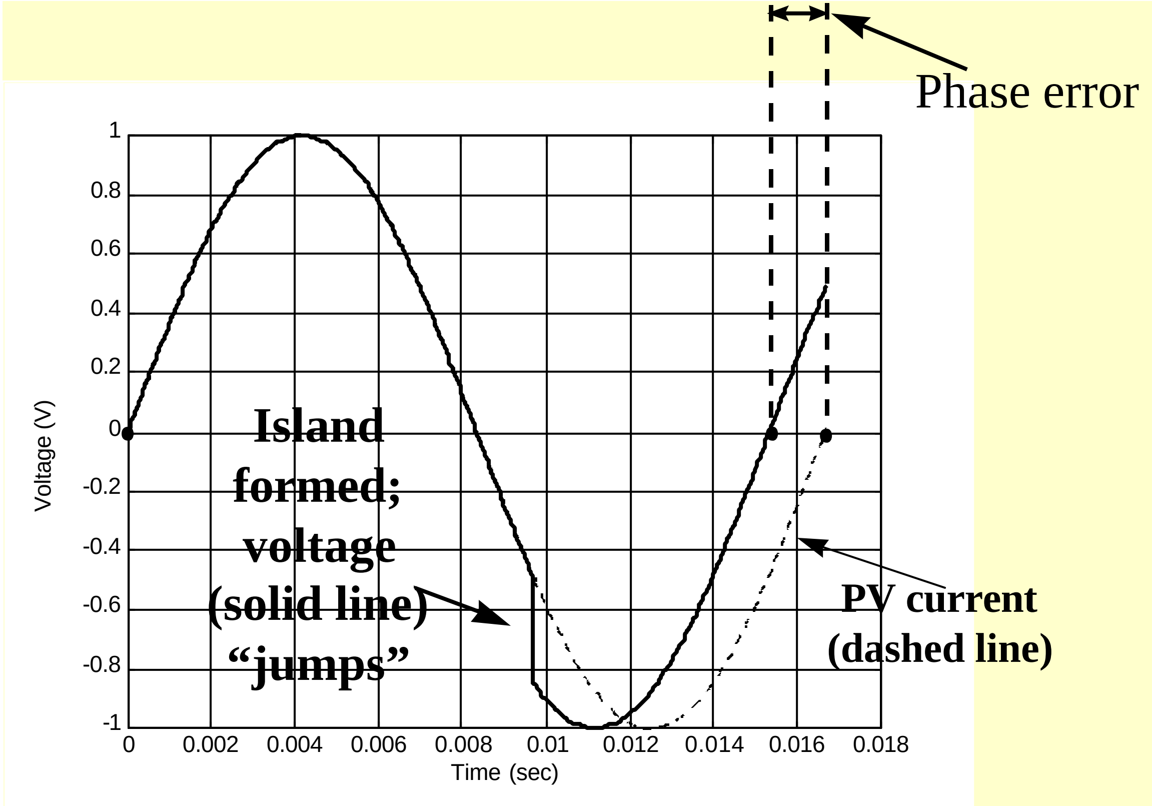
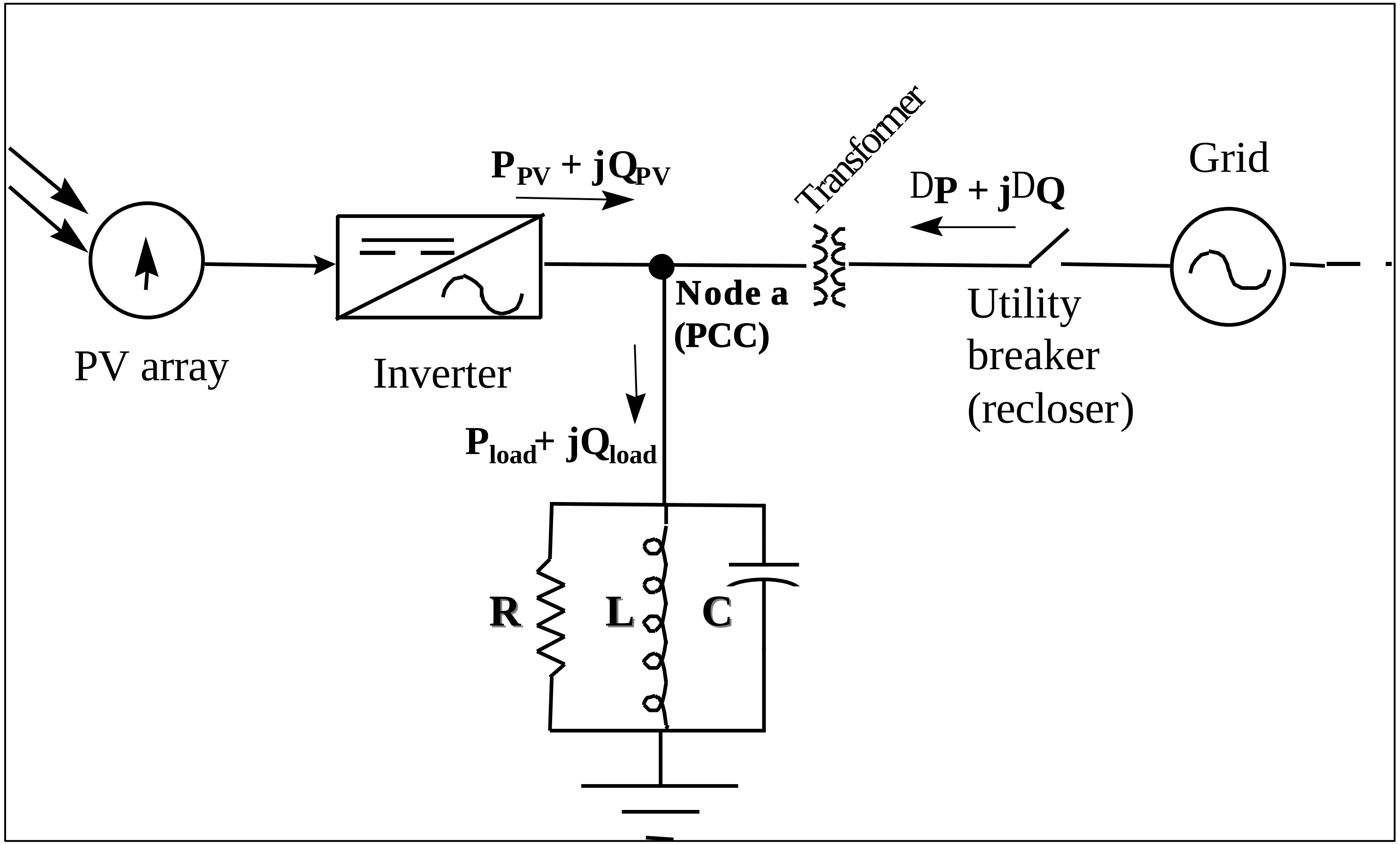


Diagram Showing the Operation of the Phase Jump Detection Method

Detection of Voltage Harmonics and Detection of Harmonics



Detection of Voltage Harmonics and PJD

Main Challenge!

Threshold Selection Can be Very Difficult—NDZ Size vs. Frequency of False Trips. Not Always Possible to Select a Threshold That Guarantees Non-islanding Without Causing Excessive False Trips.

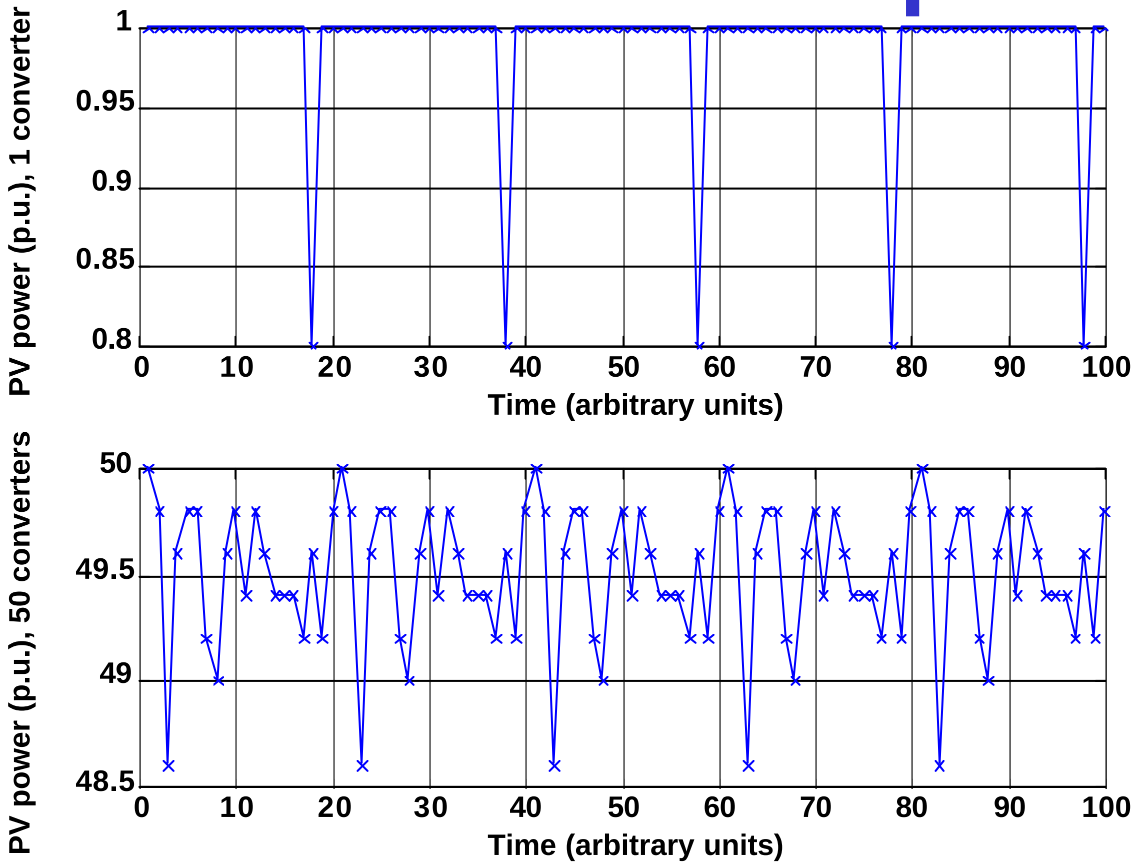
Active Methods Resident in the Inverter

Impedance Measurement

- **Also *Power Shift; Current Notching, Output Variation; Used in ENS***

Amplitude (usually), Frequency, Or Phase of the PV Output Current Is Periodically Varied. In The Case of Islanding, Upsets Balance. “Crazy Ivan”

Impedance Method Failure: Multiple Inverter



Demonstration of the Failure of the Impedance Measurement Method in the Multiple-inverter Case

Detection of Impedance at Specific Frequency

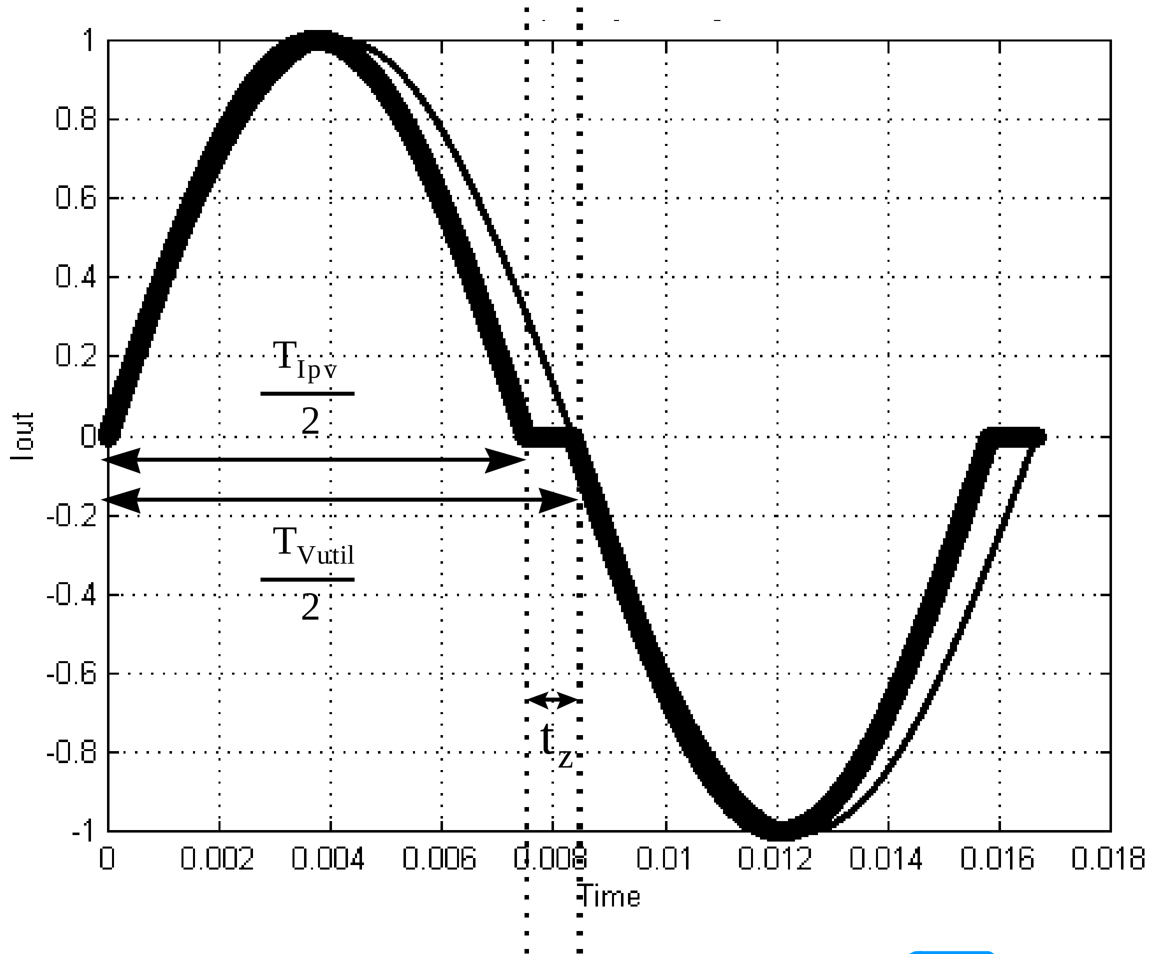
- Also *Harmonic Amplitude Jump*
  - Description: Looks for an Amplitude Increase of a Specific Harmonic (Typically Injected Into the Utility)
  - Strengths: Same as Harmonic Detection
  - Weaknesses: Thresholds Difficult to Choose, The Utility is Not a Always Clean, Local Resonance or Noise Can Cause False Trips
  - NDZ: Same as Harmonic Detection. Subharmonic Injection Can Eliminate NDZ but Is Problematic for the Utility

Frequency Bias

- **Also *Active Frequency Drift, Frequency Shift Up/Down***
  - **Description: Output Waveform is Slightly Distorted So Islanding Causes a Drift in Frequency**
  - **Strengths: Very Easy to Implement With Microprocessor Based Inverters**
  - **Weaknesses: Small Degradation in Output Power Quality,**
  - **NDZ: Relatively Large relative to Other Active Methods, Depends on the Value of the Chopping Fraction Used, Small (<1% then Same as SMS), Larger Causes NDZ to Shift Toward Capacitive.**

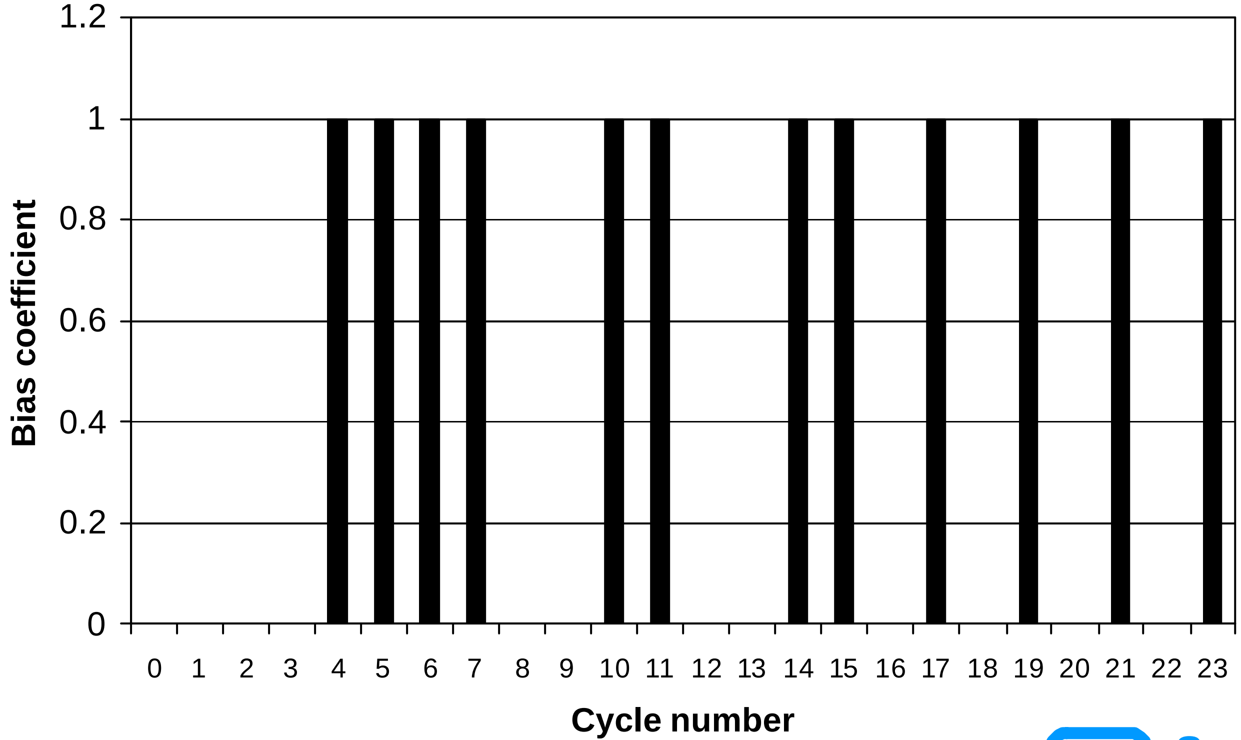
Frequency Bias

i_{PV} Goes to Zero Before or After the PCC Voltage.



Frequency Jump

- **Usually Involves a "Dithered" Freq Bias**



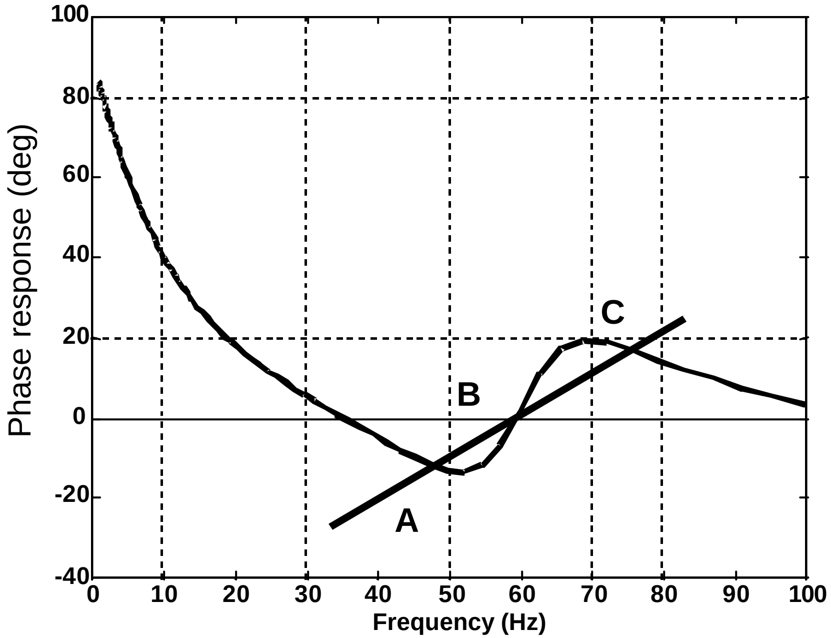
Positive Feedback Methods

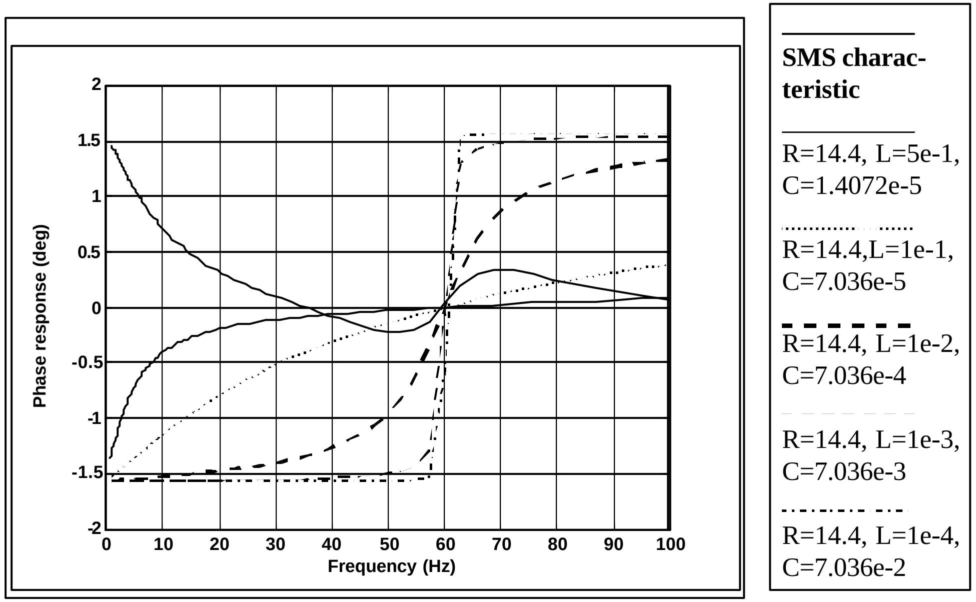
- **Slip Mode Frequency Shift (SMS): Positive Feedback on Phase of I_{pv}**
- **Sandia Frequency Shift (SFS): Positive Feedback on Frequency of I_{pv}**
- **Sandia Voltage Shift (SVS): Positive Feedback on Amplitude of I_{pv}**

Slip Mode Frequency Shift

- **Also** ***Slide Mode Frequency Shift; Phase-Lock-Loop Slip; "Follow-the-Herd".***
  - ***Note That There Are Also Similarities to the SVS and SFS Except the Acceleration (Gain in This Case) Is Nearly a Constant Value.***

Slip Mode Frequency Shift





Sandia Frequency Shift

- **Extension of Frequency Bias:**

$$cf = cf_0 + F\left(f_a - f_{\text{line}}\right)$$

where *F* Is a Gain or Function (Need Not Be Constant—Acceleration).

Sandia Voltage Shift

- **Similar to SFS Except Applied to Amplitude:**

$$I_{PV} = I_{PV,0} + F\left(V_{PCC} - V_{PCC,0}\right)$$

Where *F* Is a Gain or Function.

Summary of Positive Feedback Methods

- ☑ Very Small NDZs—High Q Loads
- ☑ Relatively Easy to Implement
- ☑ Retains Effectiveness With Multiple Inverters, esp. With ACCELERATION
- ☒ Require a Reduction in Power Quality (but Usually Manageable)
- ☒ Can Lead to Problems on Weak Grids

Mains Monitoring Units with Allocated All-pole Switching Devices Connected in Series (MSD)

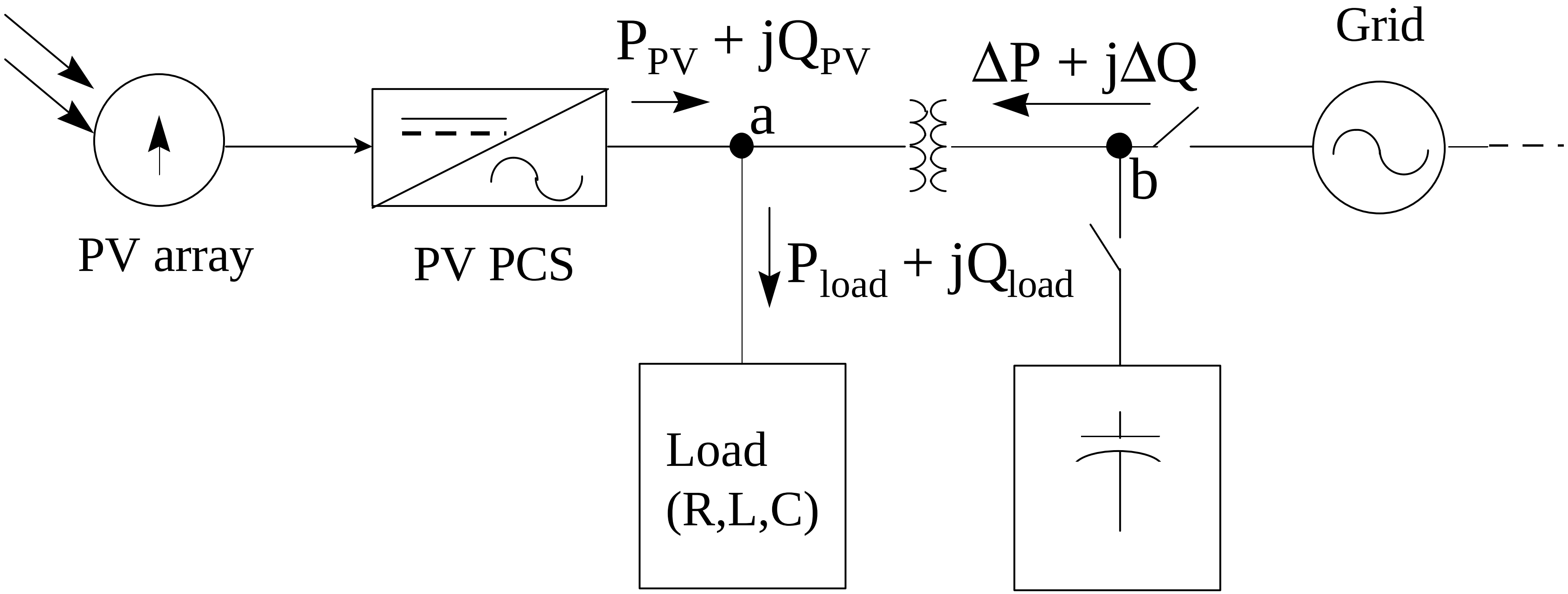
- **Also *ENS***
  - Description: Looks for a Sudden Change in Impedance with Additional Over/Under Voltage and Frequency Circuits
  - Strengths: Redundant Methods, Self Check for Reducing Need for Periodic Retesting.
  - Weaknesses: Interference with Other Units with Multiple Inverters, May Result in Nuisance Trips, Multiple Units Dilute the Effectiveness. Impedance Detection Range Will Change with Higher Rating of Inverter or the Utility Grid Characteristics.
  - NDZ: All Voltages, Frequencies and Impedances Within the NDZ. NDZ Increases With Multiple Inverters.

Methods at the Utility Level

- Typically for Large System Interconnects
- May be The Only Anti-islanding Protection
- Set Points Controlled by the Utility
- Interactive Communications Often Involved

Impedance Insertion

- **Also Reactance Insertion, Resistance Insertion**



Methods Using Communications Between the Utility and PV System

- **Power Line Carrier Communications**
- **Signal Produced by Disconnect**
- **Supervisory Control and Data Acquisition (SCADA)**

Summary

- The Rationale For Anti-Islanding Shows There Is a Need to Include Detection
- Rationale For Testing and Test Methods Shows a Need For Accuracy & Consistency
- Standards and Codes Are Being Drafted and Implemented
- Inverter Resident and Non-Resident Methods Presented
- Passive and Active Detection Methods Described with Strengths & Weaknesses

Summary

- **Task V Has Positively Impacted the Anti-islanding Understanding and Progress Through Workshops and Collaborative R&D**