Advancing Anti-Islanding Testing with Power Hardware-in-the-Loop

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Motivation

Anti-islanding requirements

Important protection function

Local detection methods

Compliance testing

Expensive in equipment costs and time

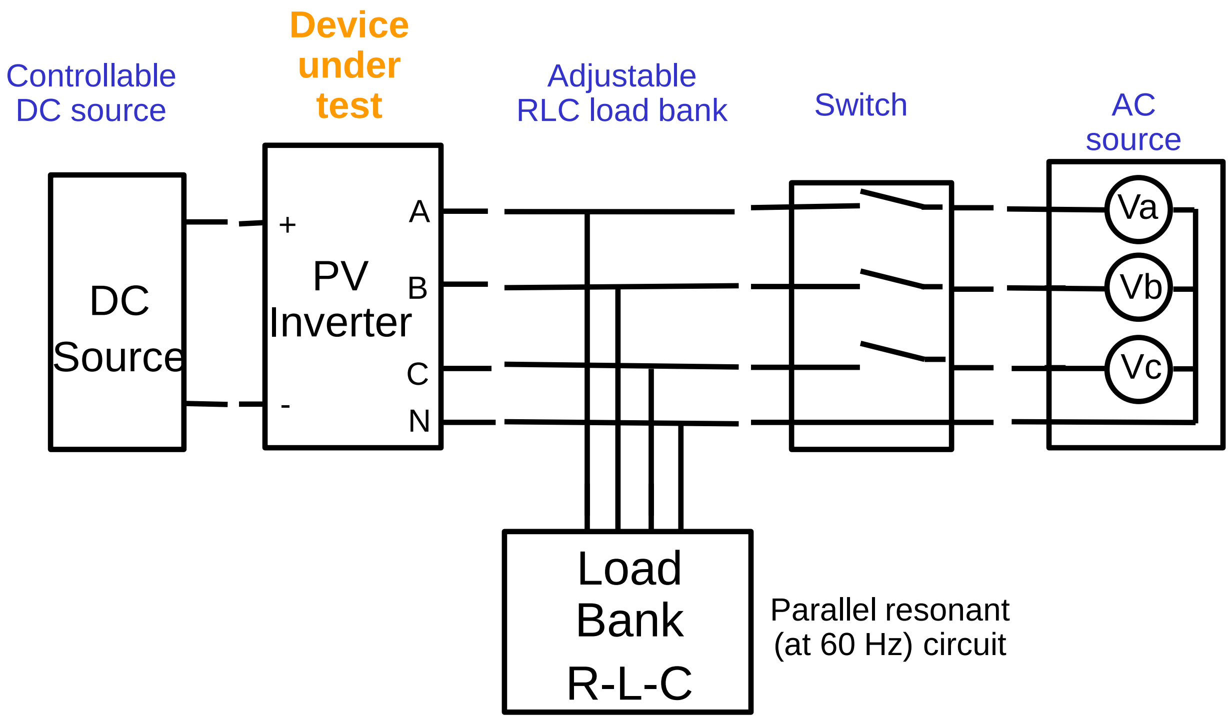
Impact of advanced inverter functions

Alternate approach feasible?

Can PHIL replace RLC load banks

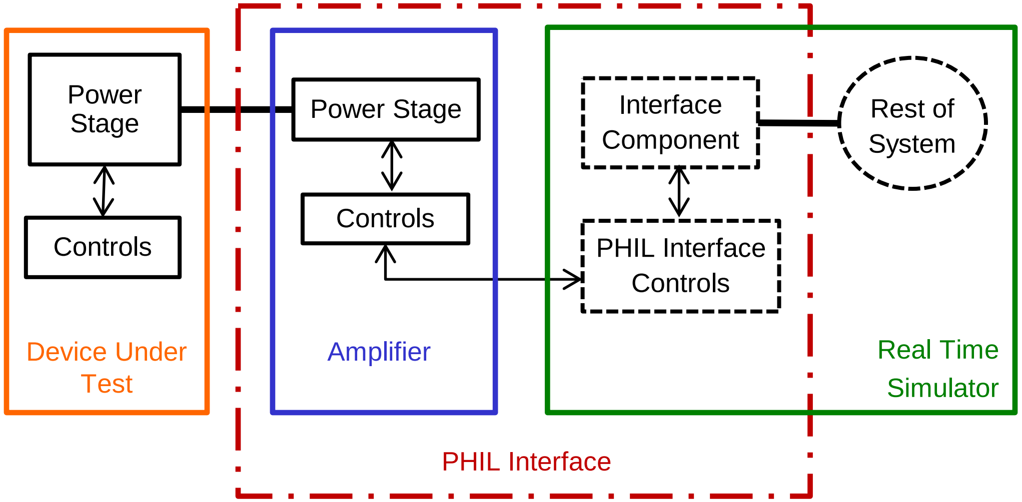
Feasibility and challenge of alternate conditions

Unintentional Islanding Test
IEEE 1547.1

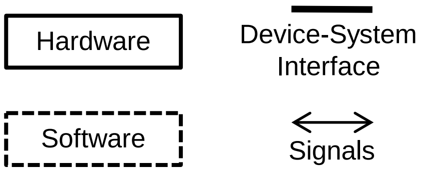


- PV output matches resistive load (100%, 66%, 33%)
- Quality factor of Qf = 1 (plus 5% variations)
- Two seconds to detect and cease to energize
  (though recloser considerations may require shorter times)

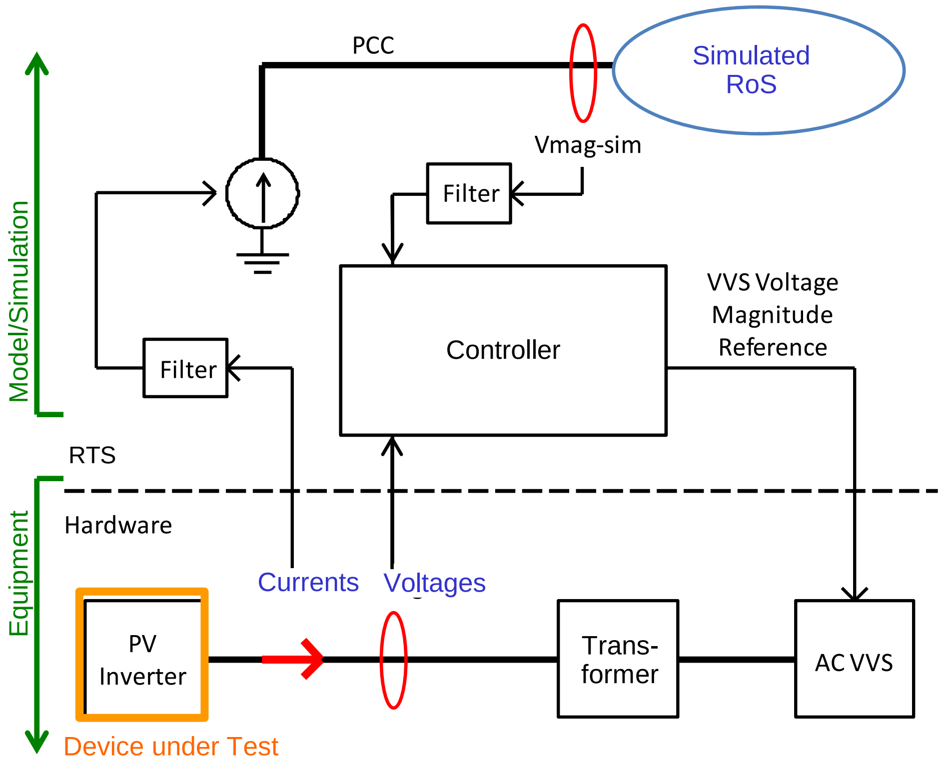
Power Hardware-in-the-Loop Principle



What does it take to set up a PHIL simulation?

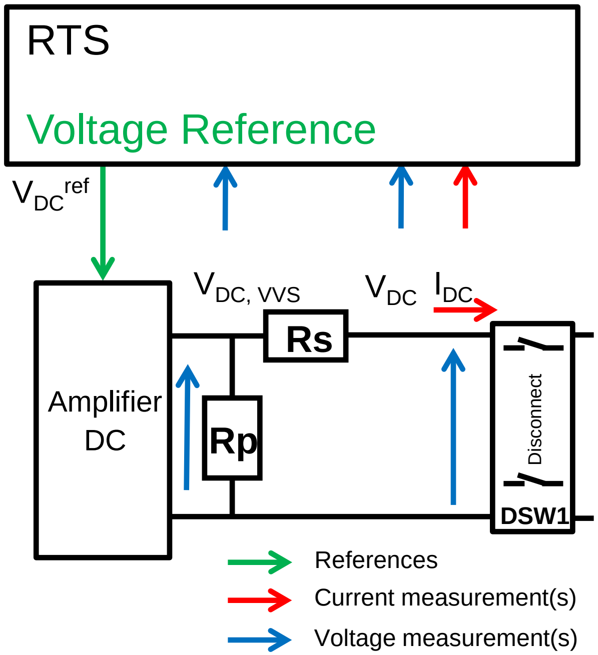


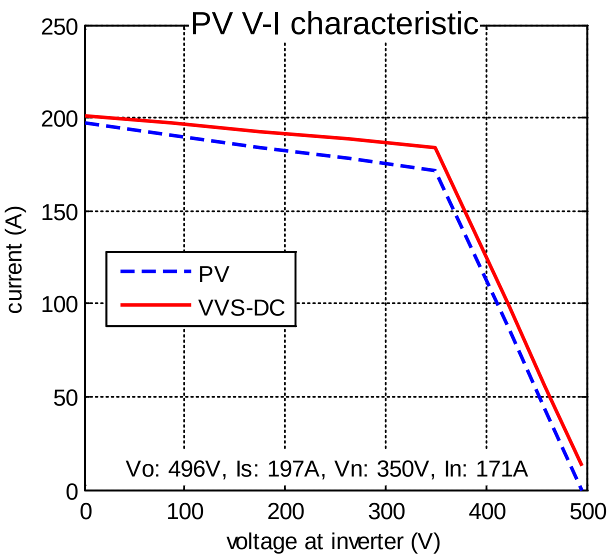
Power Hardware-in-the-Loop Principle

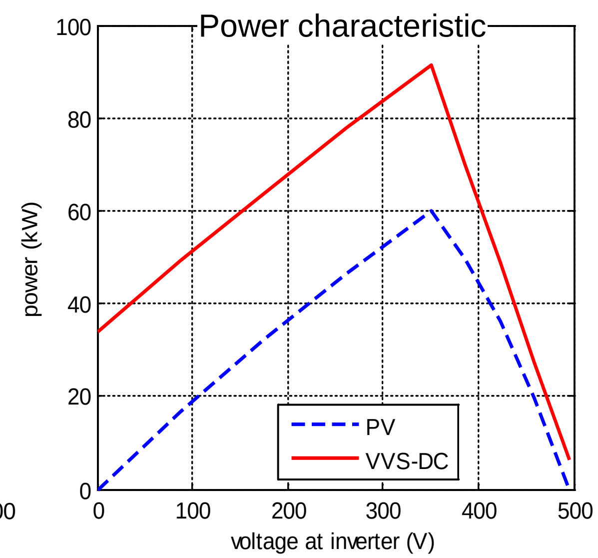


An example of how to interface and interact with device under test.

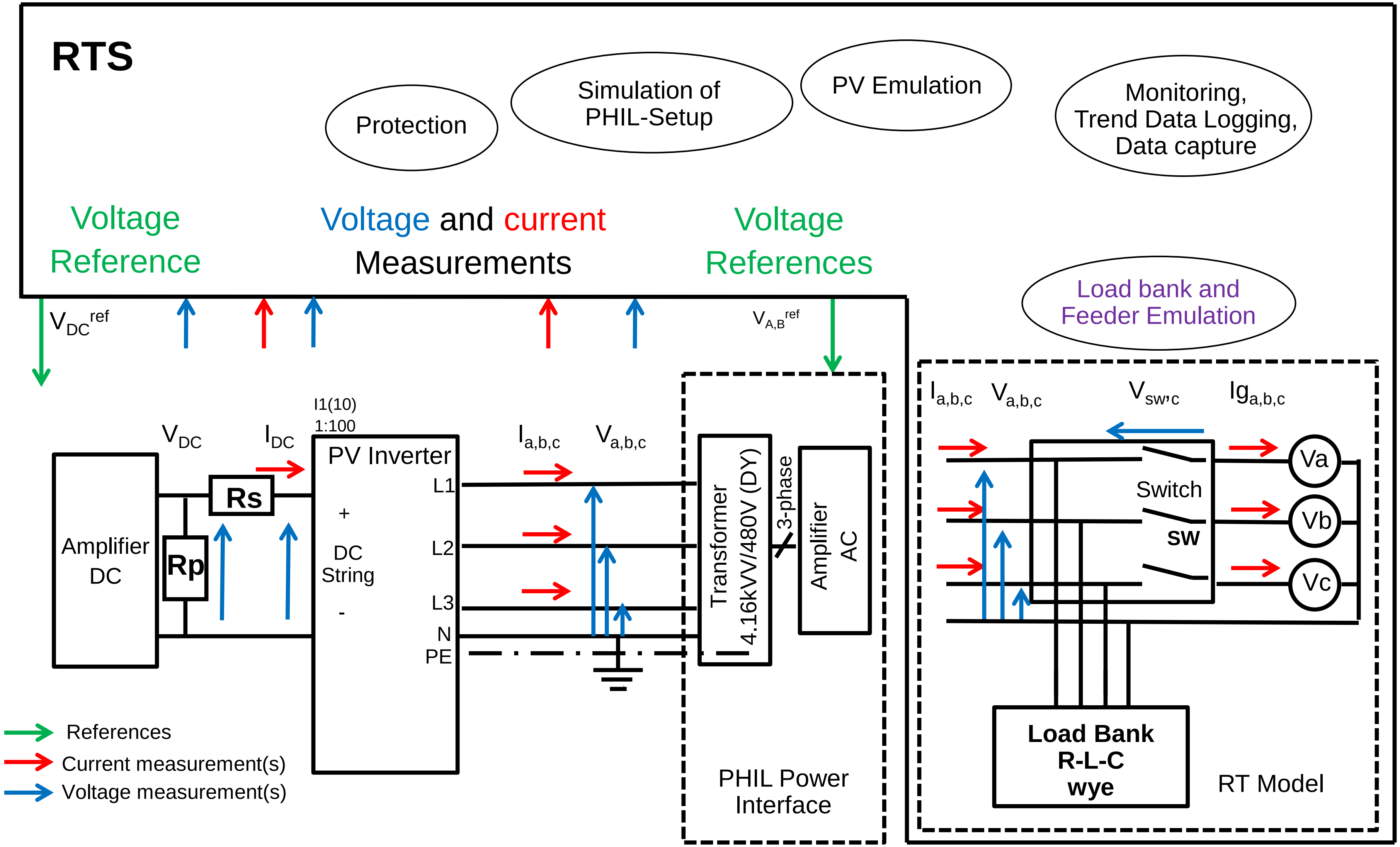
- Resistors provide damping and allows voltage or current-source mode
- Choose PV array characteristic and compute reference voltage-current characteristic
- Controlled DC power amplifier







Example PHIL Test Setup



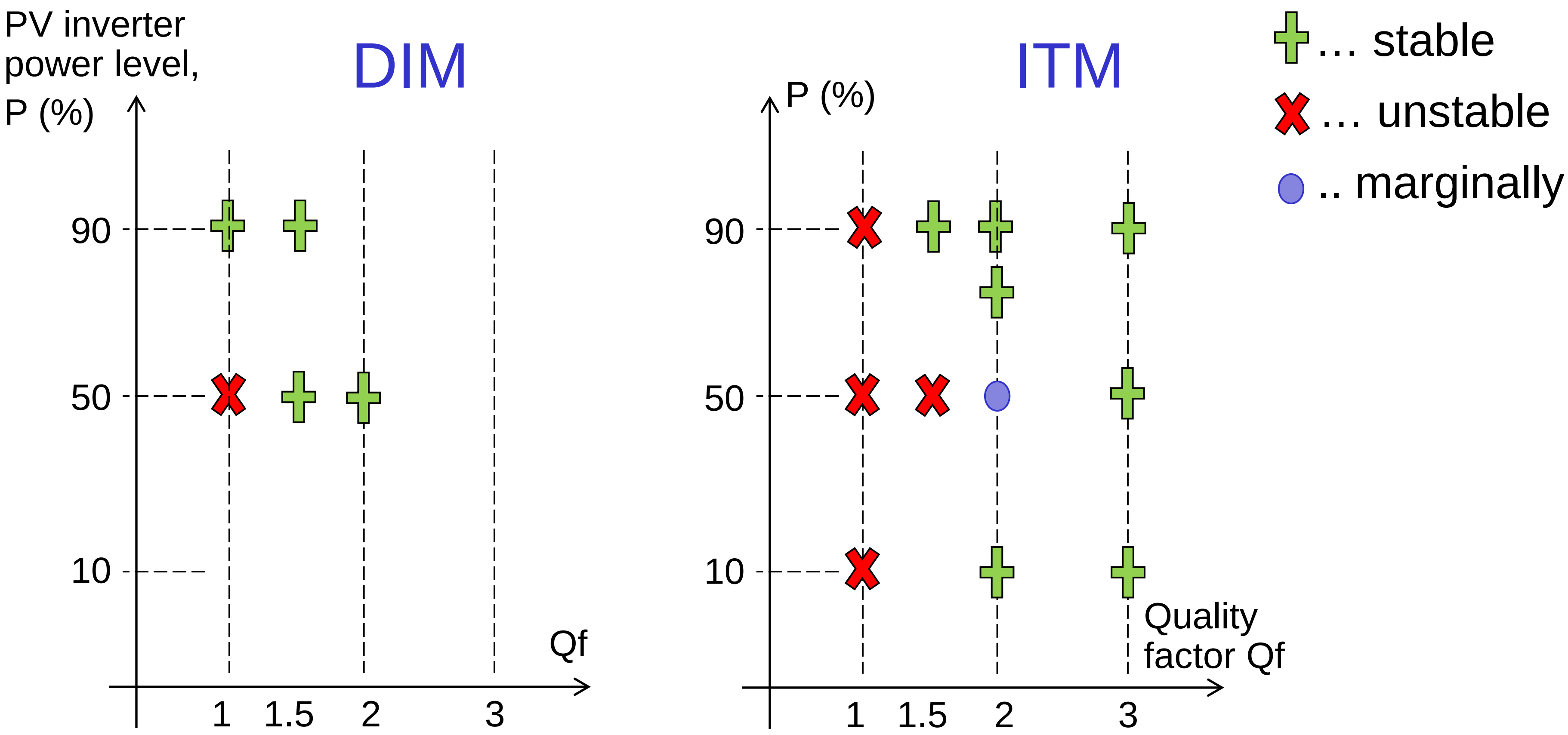
PHIL Interfaces

- Reference frame based approaches
  - Enhanced PLL for AC-voltage tracking
  - Positive and negative sequence tracking with decoupled double synchronous reference frame
- Instantaneous Ideal Transformer Model (ITM)
  - Simple from an implementation standpoint
  - Region of stability smaller than compared to DIM
- Instantaneous Damping Impedance Method (DIM)
  - Current and voltage fed back into RoS-model PHIL interface
  - Need to know or estimate impedance

Tests Performed

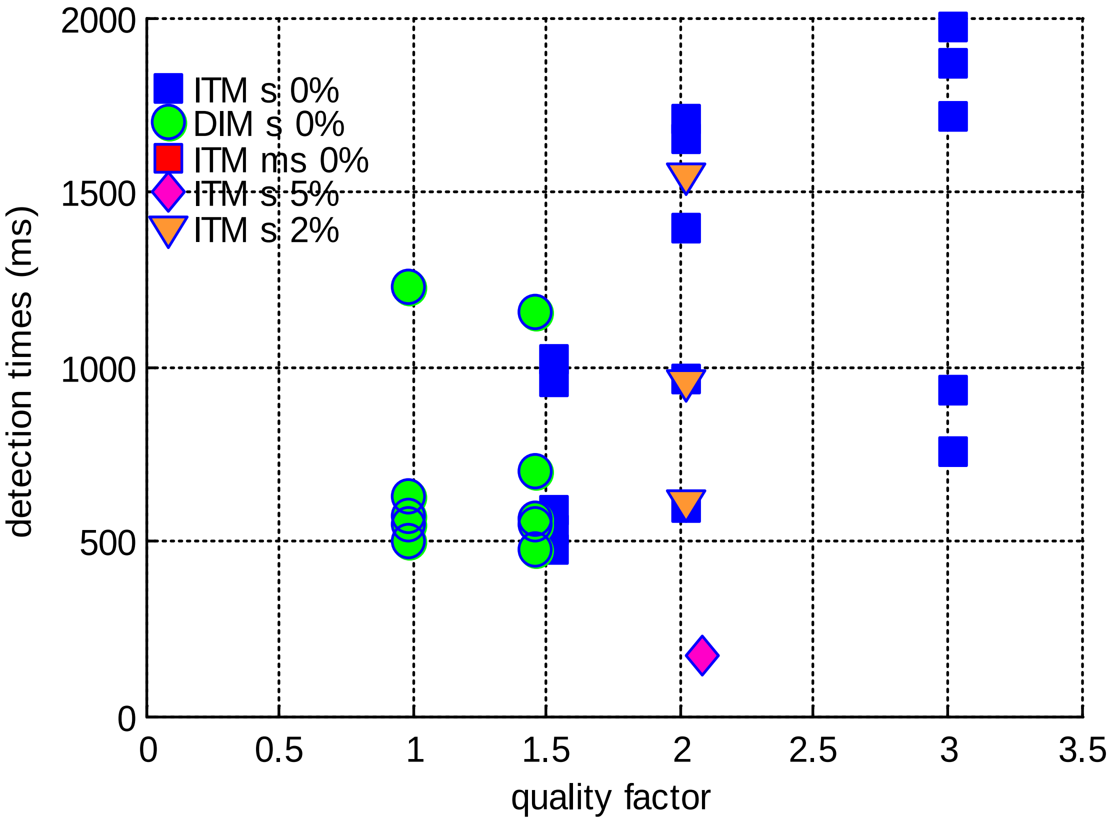
- RLC-load bank
  - Quality factor: 1, 1.5, 2, and 3
  - Mismatched reactive power
  - (Some) compared to actual load bank tests
- Induction motor
  - Inertia load and capacitor banks for power factor correction
  - Equivalent quality factor
- Inverters modeled as constant power injections
  - Reactive power controls

PHIL Results: Load bank conditions and stability



- PHIL not stable for all selected operating conditions.
- DIM helped extend stable region.

R-L-C Detection Times vs. Quality Factors



Condition: PV inverter at 90% power level.

All detected within 2 seconds.

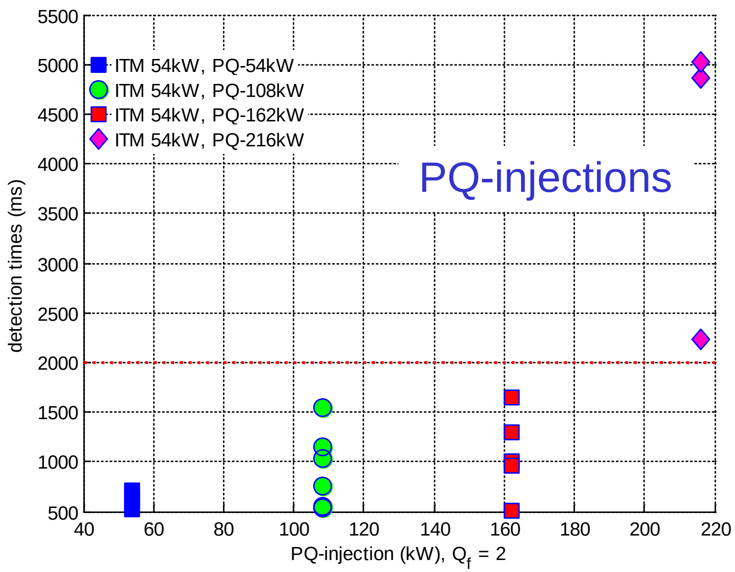
Note:

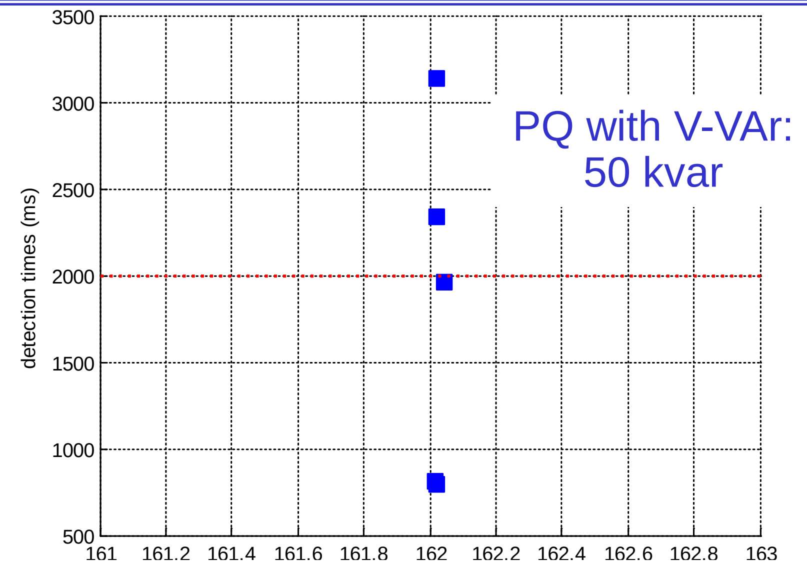
Ideal Transformer Model (ITM)
Damping Impedance Method (DIM)

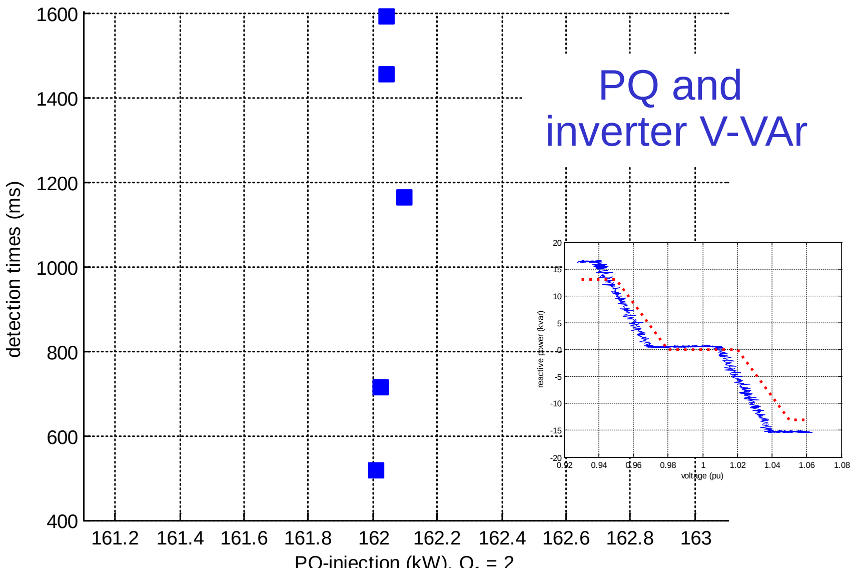
stable (s)
marginally stable (ms)

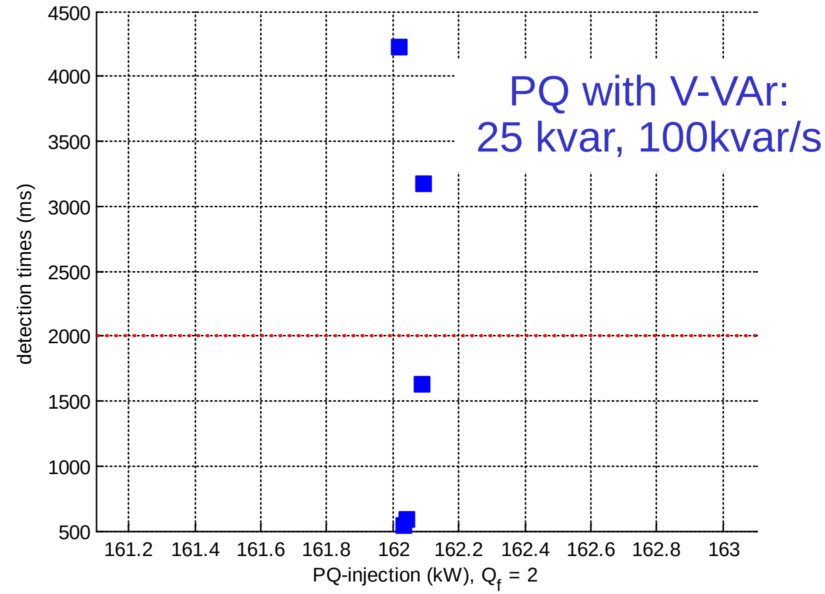
Reactive power mismatch (%)

RLC and Constant –PQ: Times vs. Power level

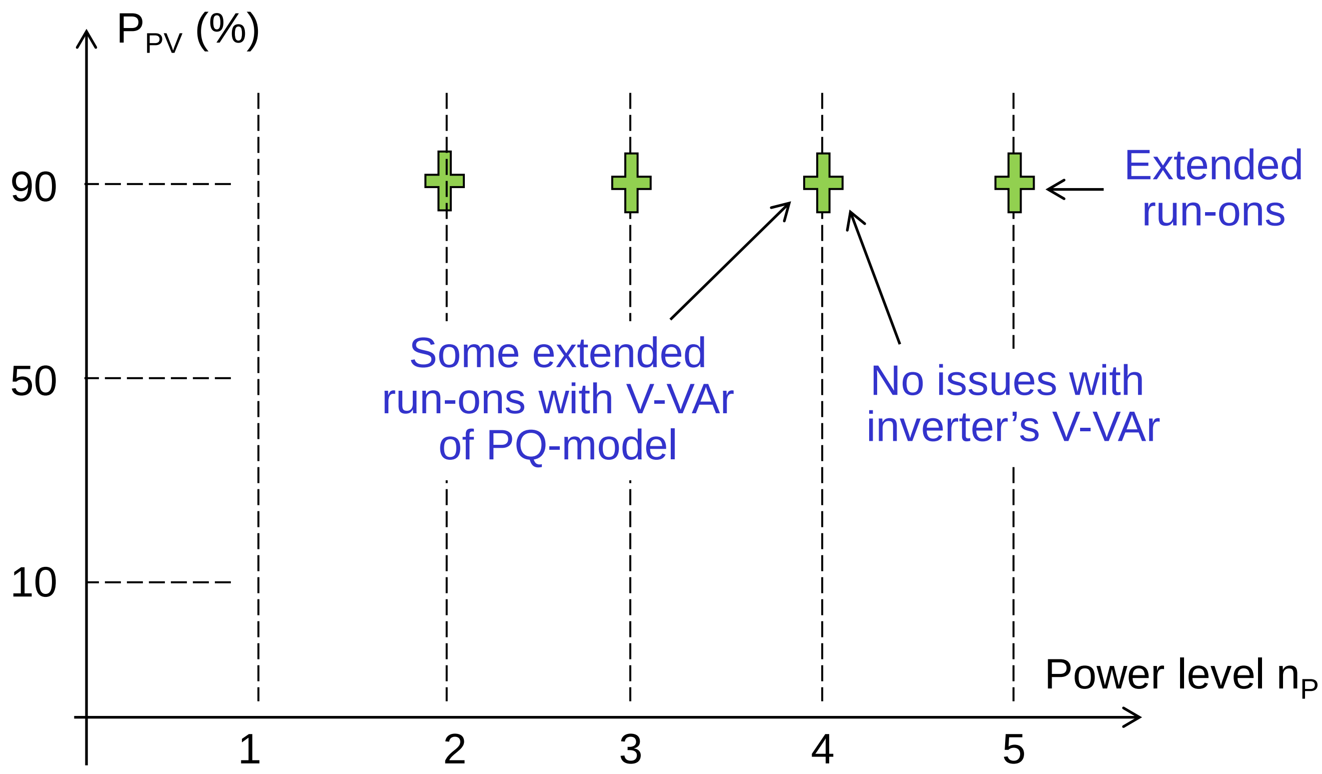








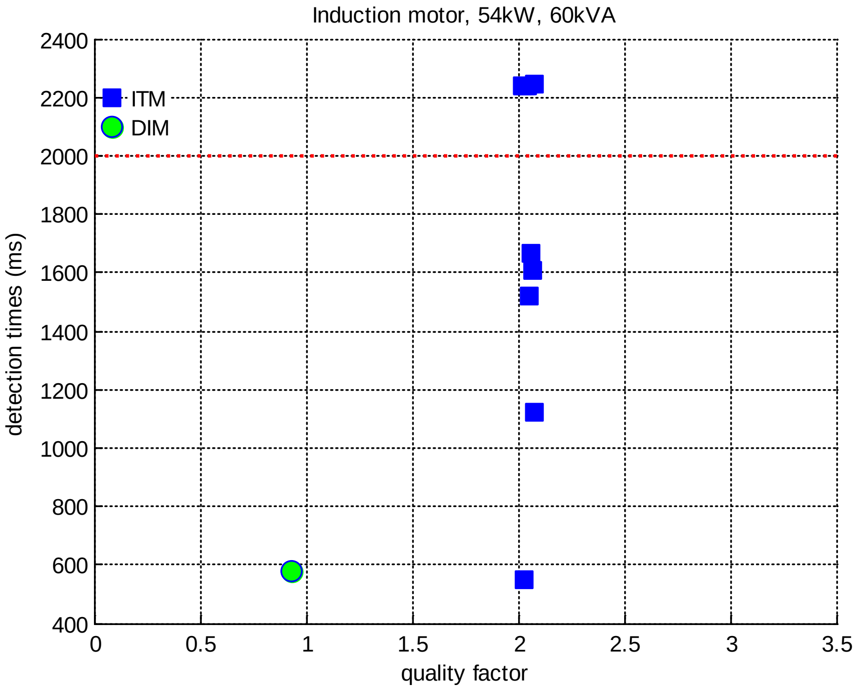
RLC and Constant –PQ: Times vs. Power level

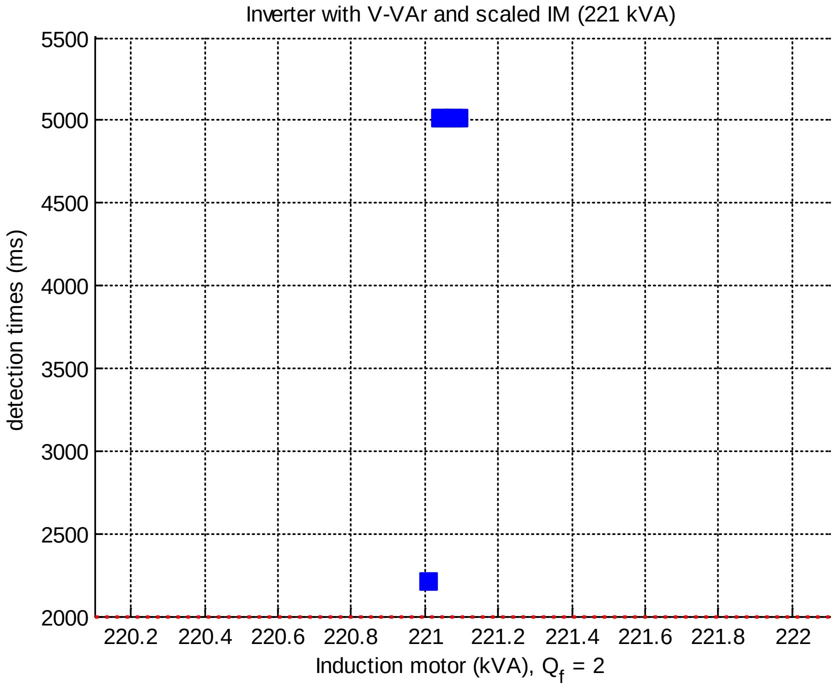


Note:

- Quality factor $Q_f = 2$ for simulated RLC load bank
- effective quality factor Q_f “= Q_f / n_P with $n_P = (P_{PV} + P_{PQ}) / P_{PV}$

Induction Motor Tests





Island not detected (5 out of 10 tests).

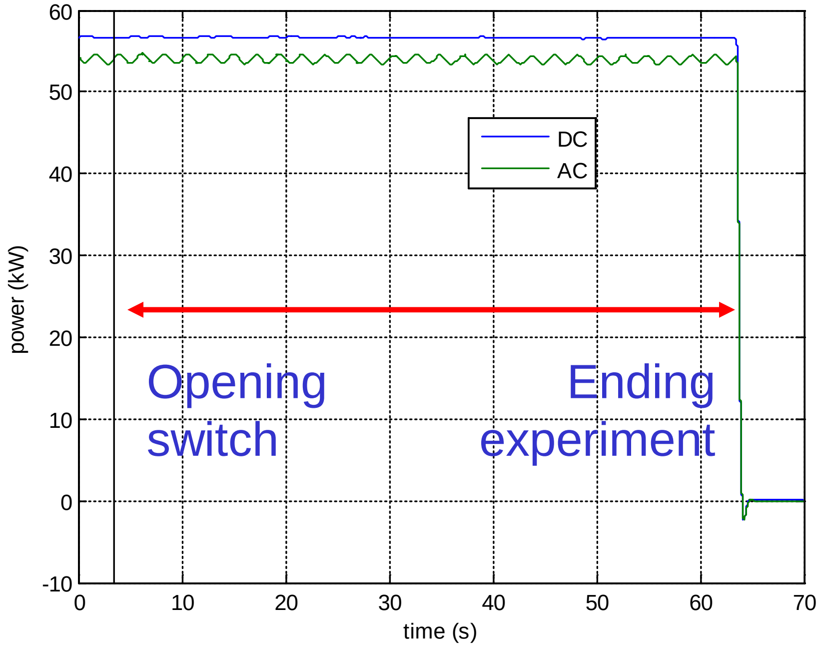
Note: Tests are halted after 2.2 seconds.

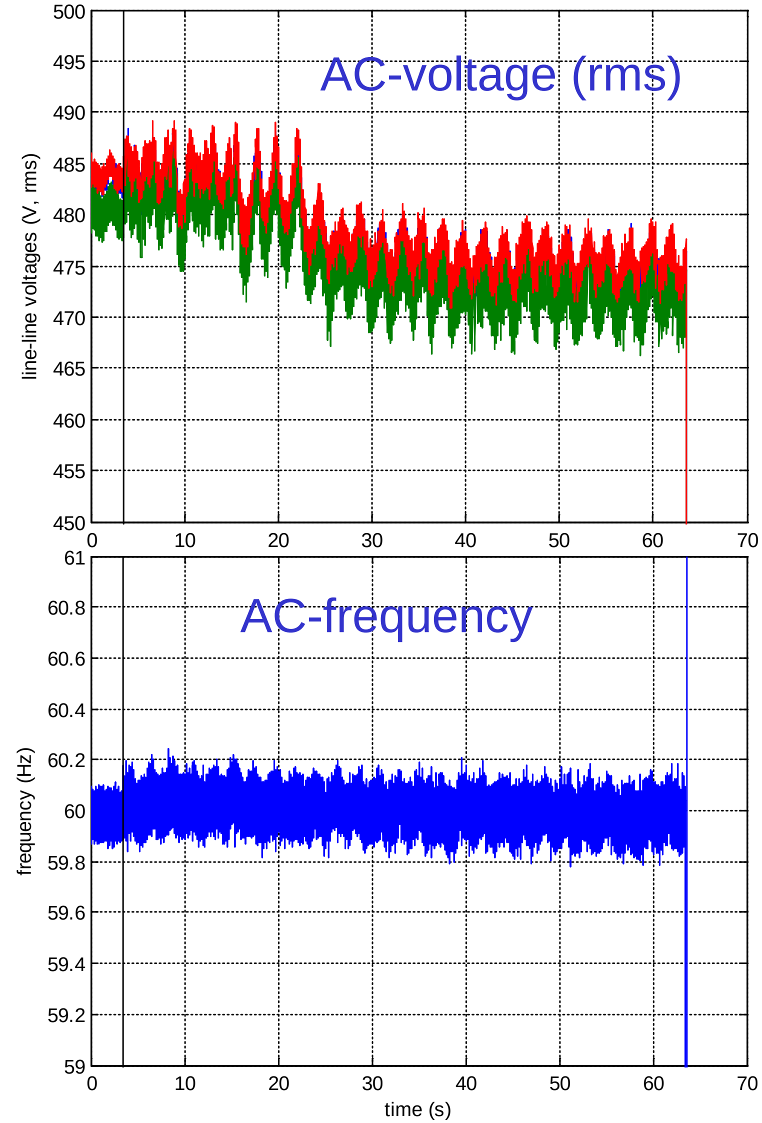
Higher-rated, lower load, Qf=2, inverter with V-VAr control: never detected.

V = 1.02-1.03pu to operate inverter in region with reactive power output.

Induction Motor Test: Run-on

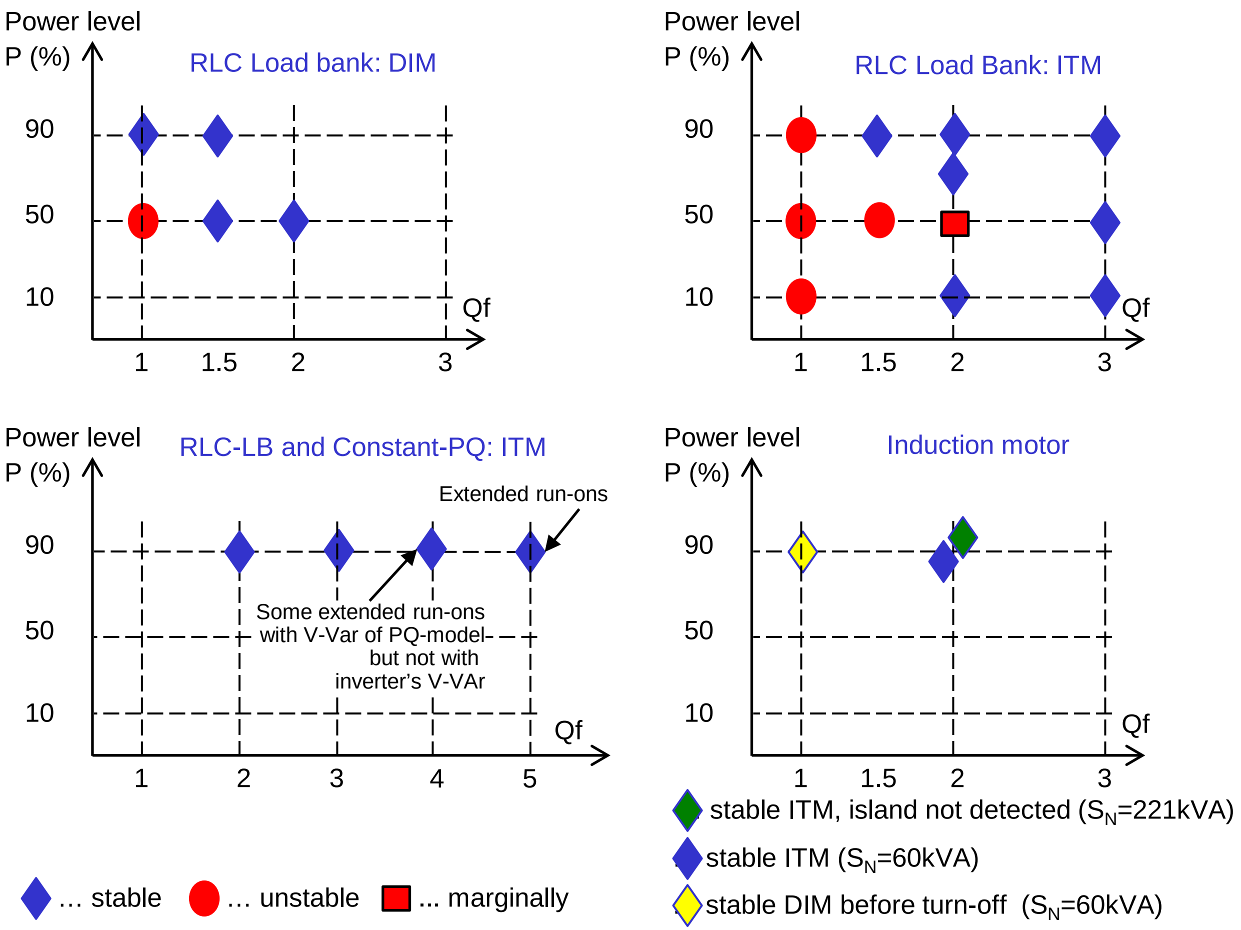
Inverter active power





Induction motor higher-rated, lower load, Qf=2, inverter with V-VAr control.

Test Condition Summary



Summary

- Evaluation of PHIL in context of unintentional islanding testing
  - Load bank and alternate conditions

- Challenges
  - Test by itself concerns an unstable system
  - Detect patterns of behavior

- Investigated several PHIL interfaces and setups
  - Improved stability aspects
  - Remaining concerns for quality factors close to Qf = 1

Final report available at
http://www.nrel.gov/docs/fy16osti/64241.pdf