Considerations for Connecting Photovoltaic Solar Plants to Distribution Feeders

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Conventional Non-Utility Generation Source Characteristics

- Engine Driven Synchronous Generators
  - Fault Current Well Above Load Current
  - Well Known Behavior During Fault Conditions
- Non Exporting
  - Straight Forward Protection
    - Sensitive Reverse Power
    - Zero Sequence Voltage Relay

Solar Facility Connection Concerns

- Utility responsibilities
- Customer responsibilities
- The solar facility maximum output
- The feeder minimum load
- The connecting transformer configuration: wye, delta, wye-grounded, etc.
- Type of converter: Utility Interactive or Utility Independent
- Other generation on the same feeder

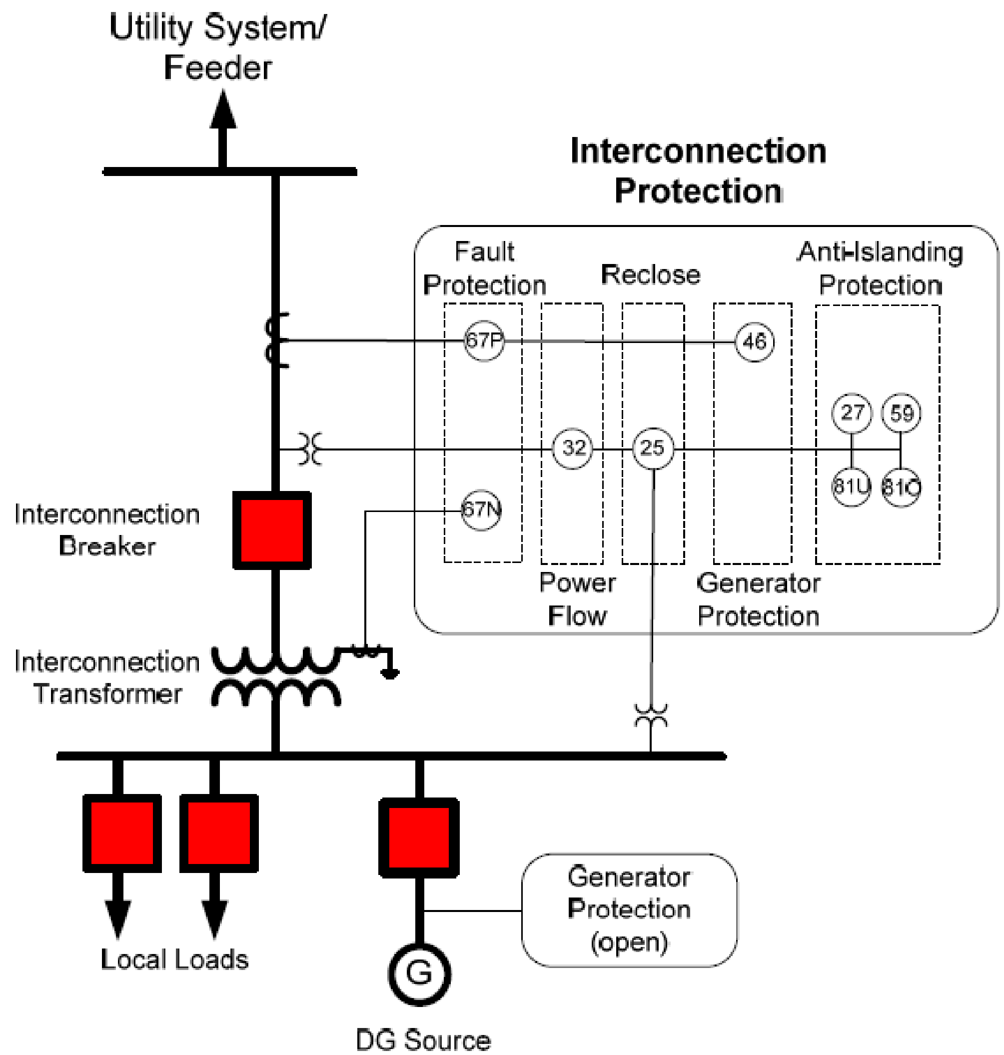
Solar Facility Connection Concerns

- Type of protective device at the utility interface
- Feeder reclosing sequence
- Interaction with automatic restoration schemes
- Will protective devices be owned by the utility or the customer?
- Will a communications aided protection scheme be necessary?
- Verification of proper operation of protective equipment

Potential Challenges Integrating DG

Challenges relate to

- Protection
- Communication
- Synchronization
- Expertise sharing



Protection-Related Challenges

- Fault current capability and short circuit analysis
  - 2-4 times rated current for 0.06 – 0.25 cycles
  - 1.2 times peak current for around 7 cycles
  - Varies by design
    - Most PV Inverters tested contributed 4-10 cycles
    - One inverter disconnected less than 0.5 cycles

Protection Schemes Considerations

- Synchrophasor-based schemes
  - Can detect islanding
  - Can detect out-of-step conditions
  - Require accurate time synchronization
  - Require reliable low latency communications path
- Communication-independent schemes, based on
  - Power factor
  - Harmonics
  - Sequence components
  - Fault current curve emulation

Communication-Related Challenges

Many interconnection projects rely on communications for fast tripping of a generator site. Direct Transfer Trip (DTT) is typically employed.

- Communication considerations
  - Leased Telecommunication Lines
  - Utility Owned Telecommunication Infrastructure
  - Wireless Technologies
  - Power Line Carrier Communications

Leased Telecommunication Circuits

- Benefits:
  - Less capital investment

- Challenges:
  - High O&M expense
  - Support for time deterministic technologies (TDM) ending
  - Ground potential rise problems
  - Availability and trouble response

Utility Owned Telecommunication

- Benefits:
  - Better cooperation between communication engineers and protection engineers
  - Faster response to communications issues
- Challenges:
  - Increased capital cost
  - Not available at many locations

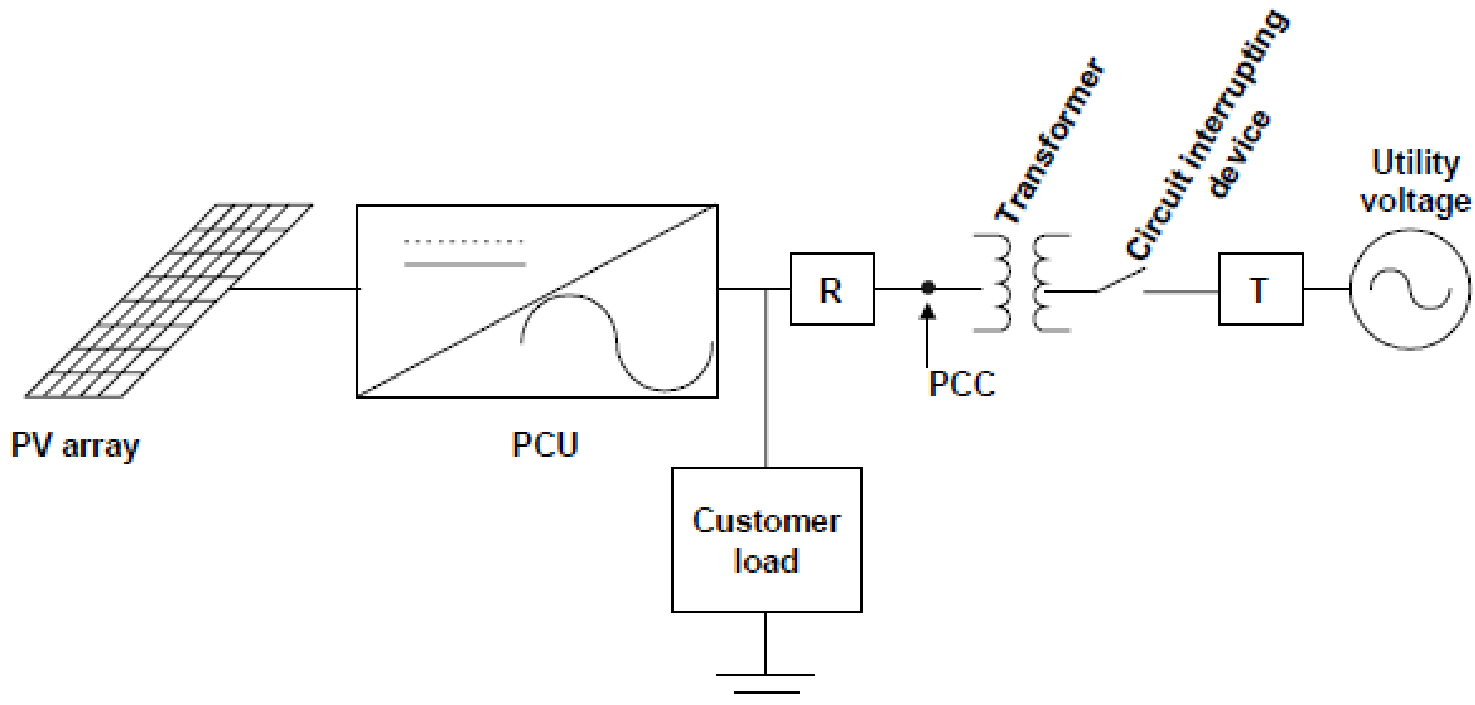
Wireless Communication Media

- Benefits:
  - May be the only technology available in rural locations
  - Eliminates the need for hardwired connections
  - Prevents problems with ground potential rise
- Challenges:
  - Unlicensed may not be suitable for critical communications
  - Licensed spectrum may involve administrative challenges

Power Line Carrier Communications

- Benefits:
  - Communications equipment specified by protection groups
  - Can transmit integrity signal from substation to customer
  - Low latency communications
- Challenges:
  - PLC signals may need to traverse transformers
  - Noise levels may be higher on distribution circuits
  - Shunt capacitor banks may weaken PLC signal

Diagram of a PV inverter system



PV Photovoltaics
PCU Power Conditioning Unit
PCC Point of Common Coupling

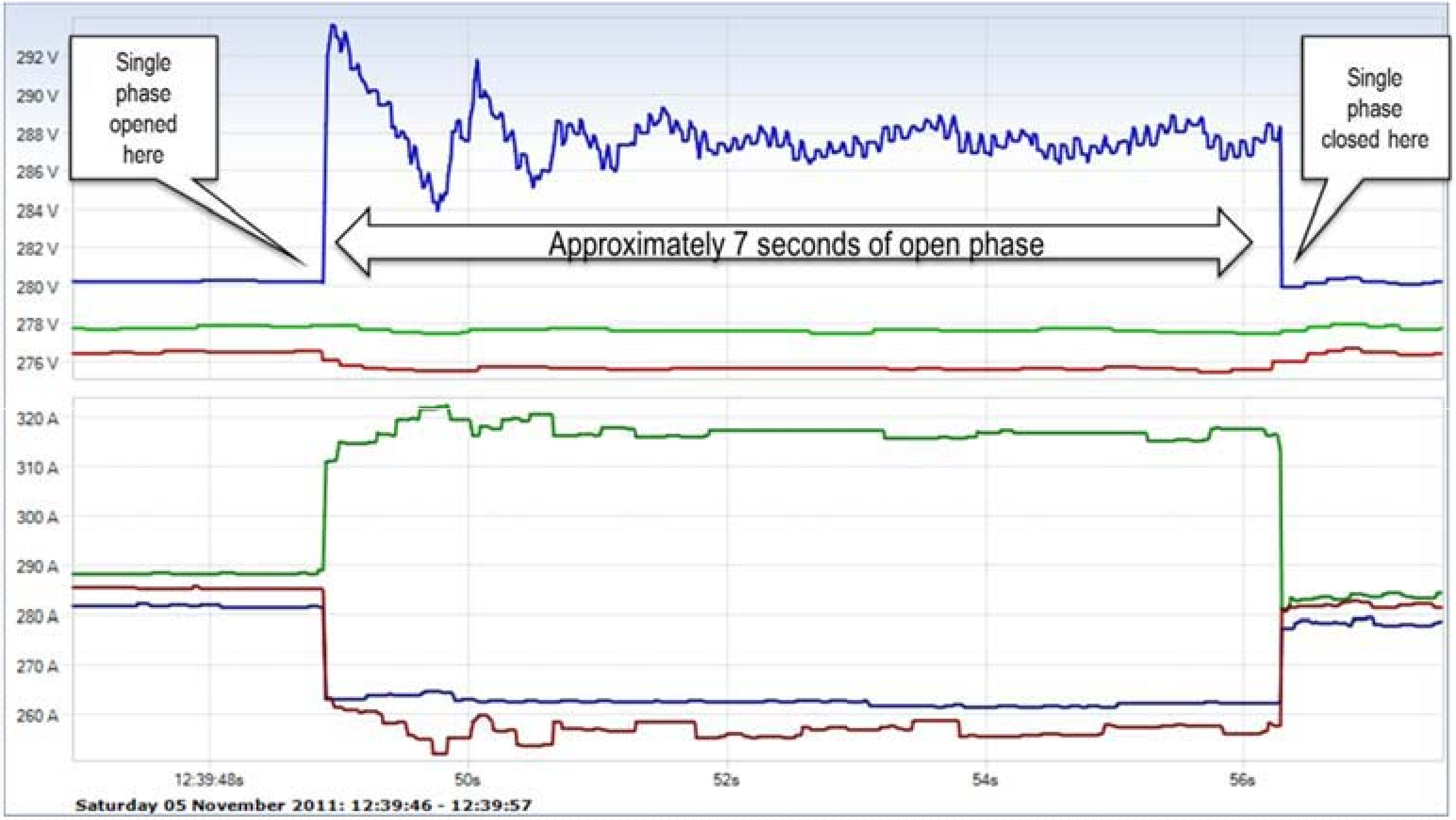
Test Experiences With PV Inverter Installations

- A Common Misconception Is That Inverters Listed As Being UL1741 Compliant Will Not:
  - Island
  - Cause transient over voltages
  - Produce power when single phased
  - Produce power at anything except unity power factor
  - Produce power within 5 minutes after an outage
  - Regulate the local voltage
  - Cause Radio Frequency Interference

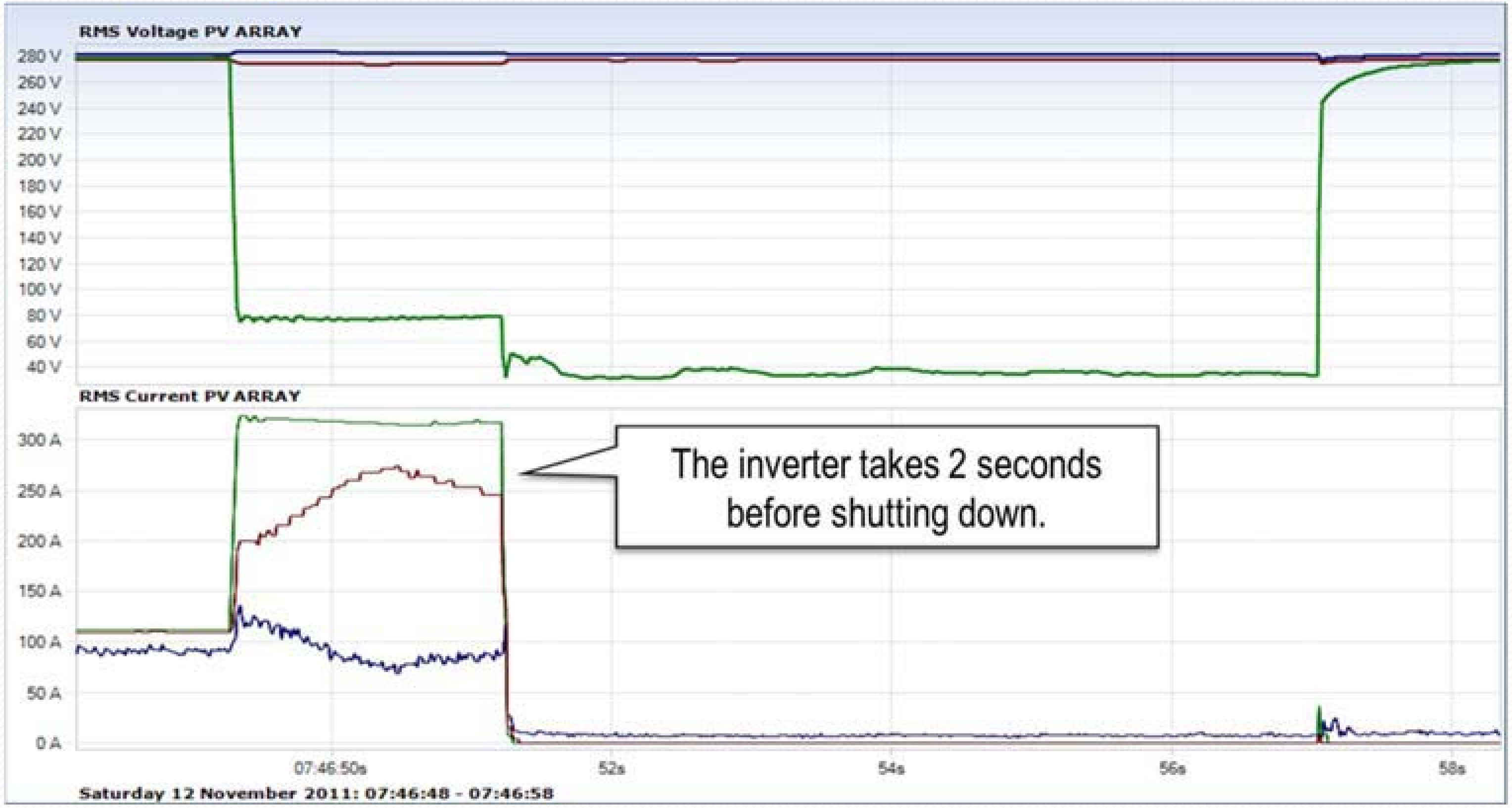
Single Phase Disconnect Test

- Requires that one phase be disconnected from the utility source on the utility side of the point of common coupling (PCC) and the response of the facility be measured at the PCC
- To pass the test, the facility must stop producing power within a specified time – usually 2 seconds
- The test can be performed by disconnecting either a riser fuse or bay-o-net fuse upstream from the PCC
- The fuse must be disconnected and reconnected to reduce the time spent single-phasing the transformer

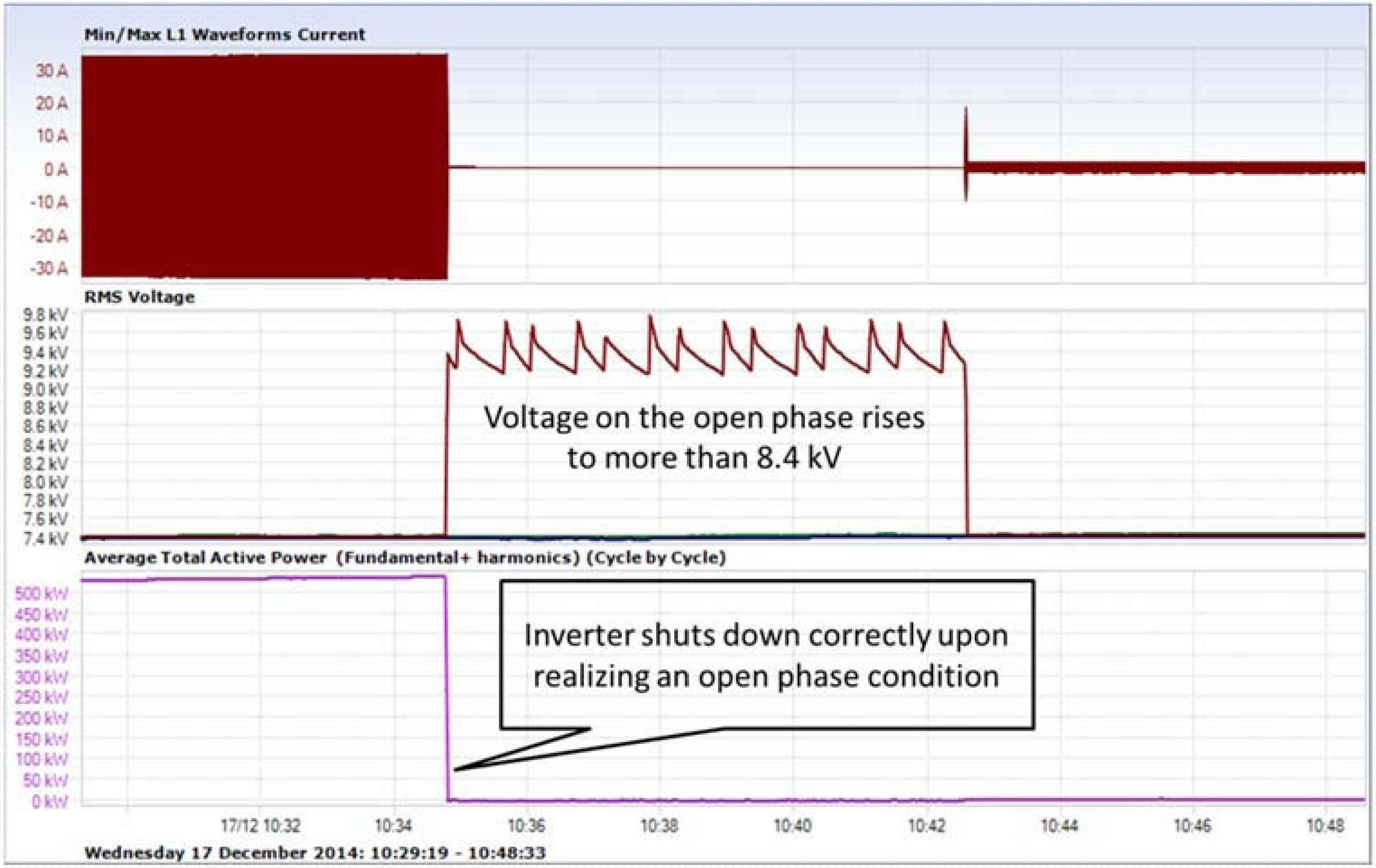
Facility Failing To Detect Single-Phasing



Action After Inverter Reprogramming



Fault Recording – Normal Operation



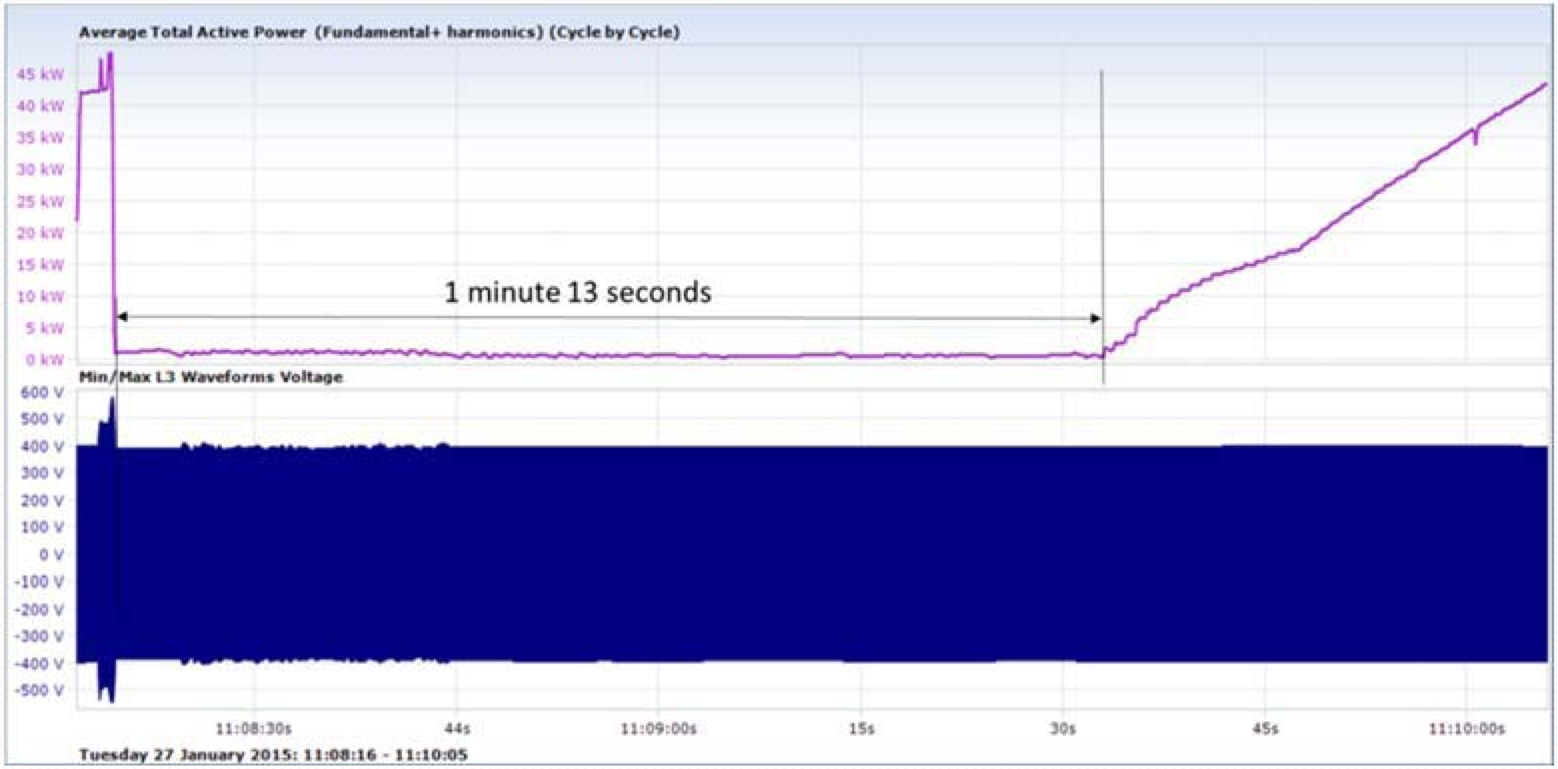
Lessons Learned

- Keep single phase open test times as short as possible. Three seconds should be sufficient to know if the inverters responded correctly. This is best achieved by pulling bay-o-net fuses and simply replacing them after three seconds
- Verify that surge arrestors are capable of withstanding the expected over voltage on the open phase
- Check the disconnecting device for any abnormalities if possible such as cracks in insulators or low oil in transformer
- Listen to the transformer. If the growling suddenly stops before the fuse was closed in, disconnect the transformer and inspect

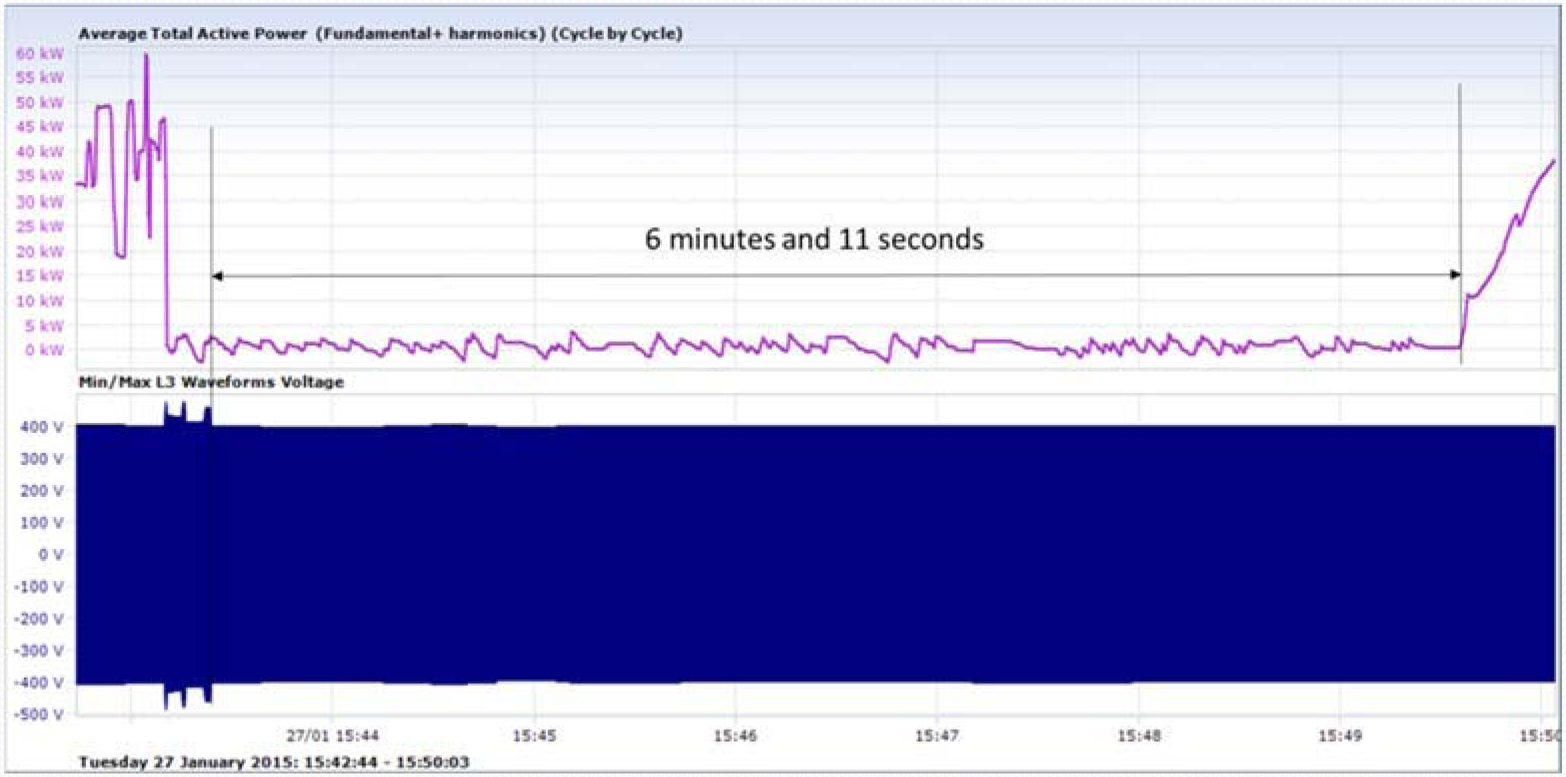
Checking Generation Start-up Time

- After a disturbance on the Distribution system has caused the generating facility to stop producing power, the facility is expected to wait a pre-determined time before starting generation again. In this case, once all phase voltages have been restored and have been stable for a minimum of 5 minutes, the generating facility will be allowed to start producing power again. After each disconnect test, the time of reconnect is measured.

Inverter Failing Reconnect Time Delay Test



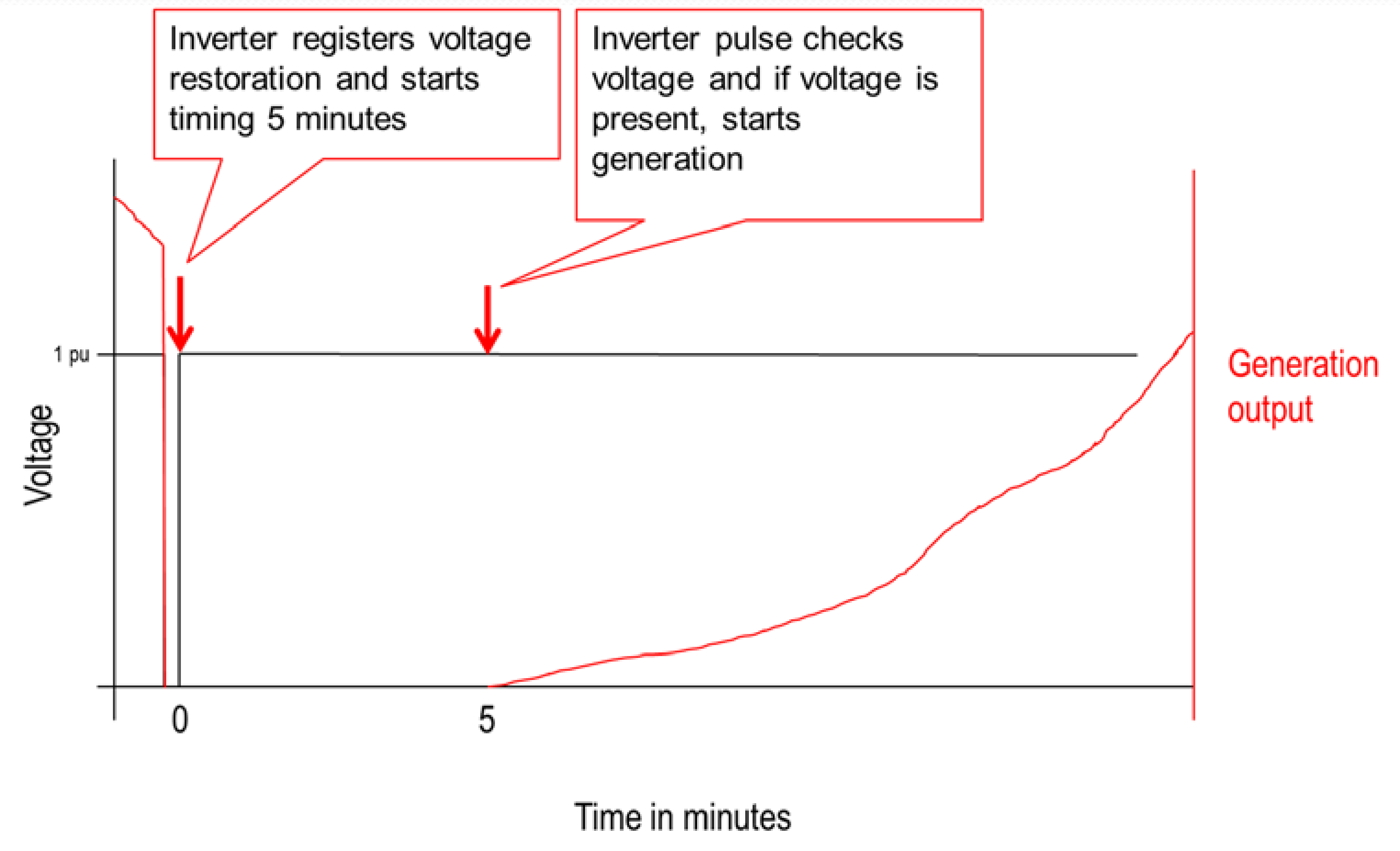
Reconnect Time Delay Test After Inverter Reprogramming



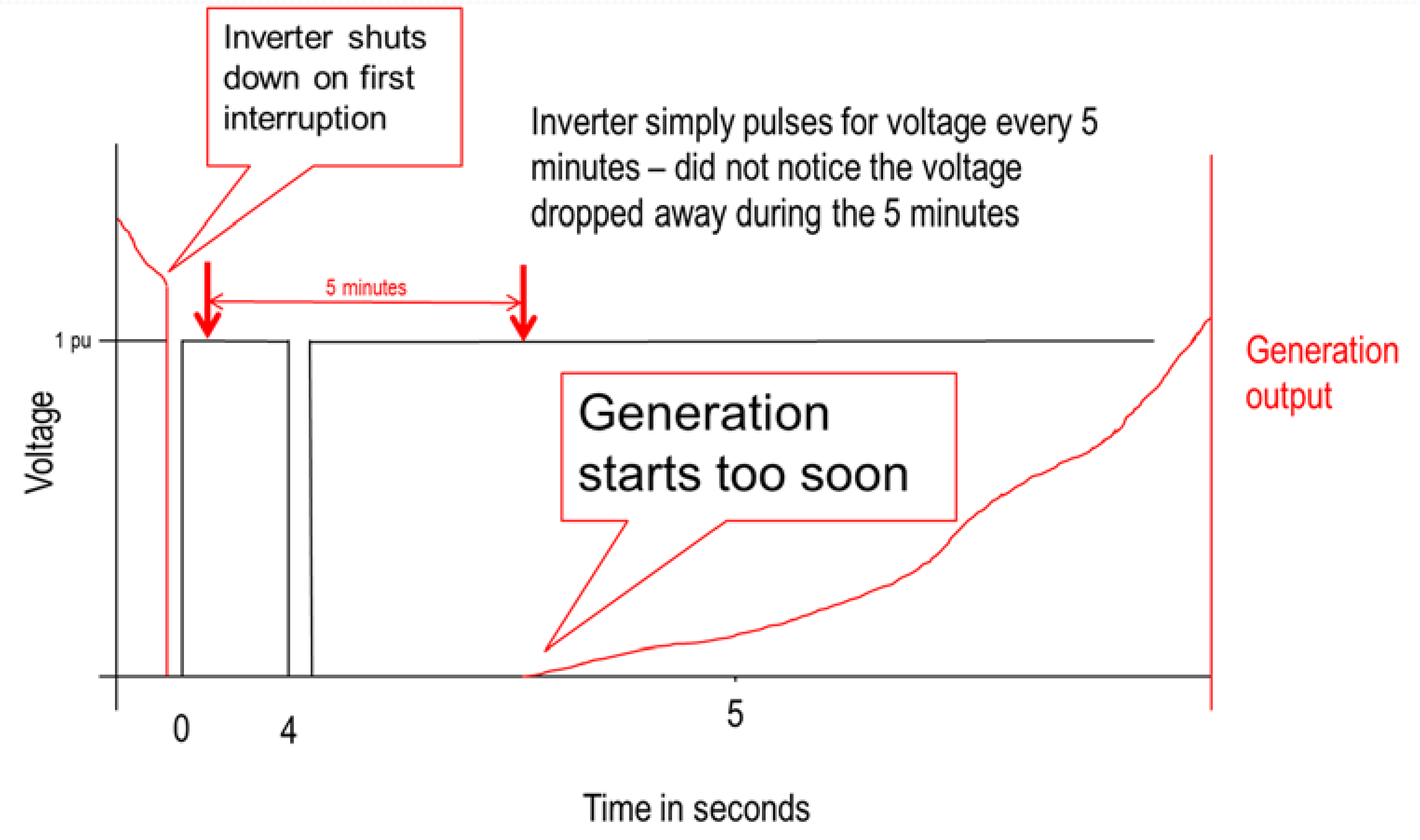
Test Experiences

- Always check the generation startup time after any disconnect test, three phase or single phase
- It is a good idea to vary the three phase open time
- Inverter pulse testing can lead to incorrect inverter reconnect time

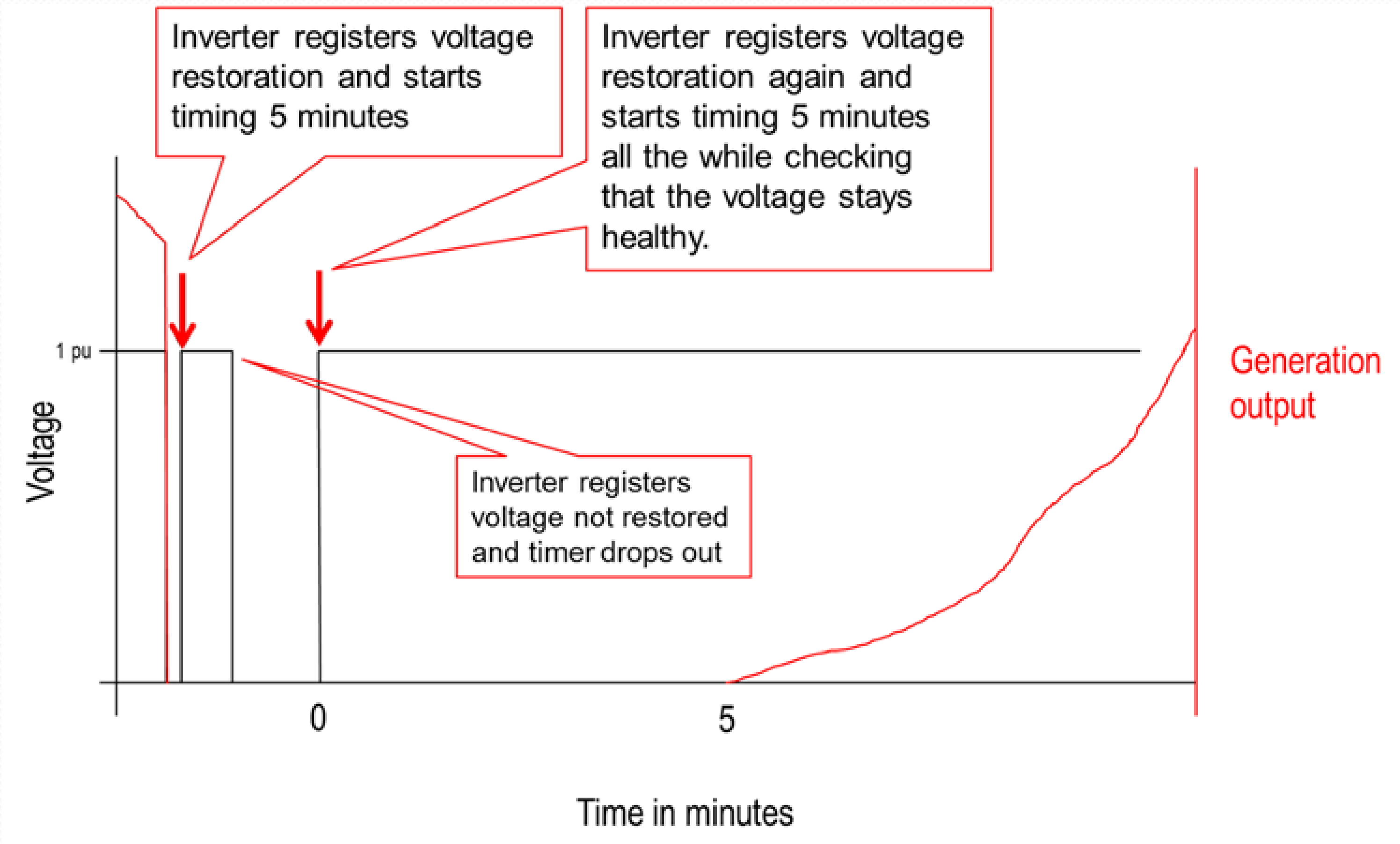
False Test for Reconnect Timing



Incorrect Reconnect Timing Exposed



Correct Reconnect Timing Sequence



Lessons Learned

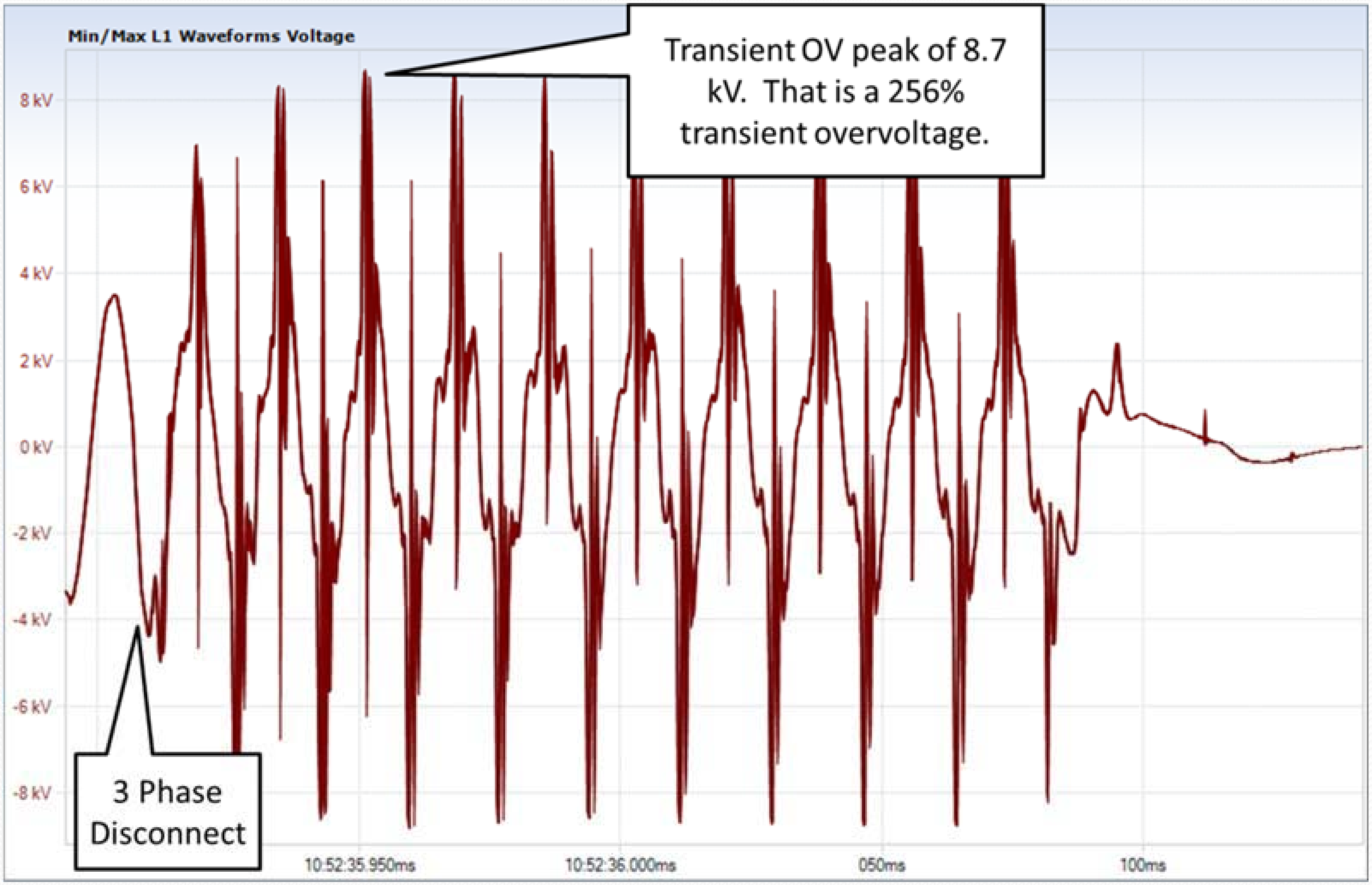
It is easy to misinterpret a 5 minute delay on startup as being correct. Here are some ways to check for issues:

- Vary the restoration time after three phase disconnect tests
- For a 5 minute restart time, open the three phase switch again after "X" minutes and immediately close it back in again, start timing from the last close
- Repeat the test at different delay intervals between open and closing, simulating reclose shots of upstream devices

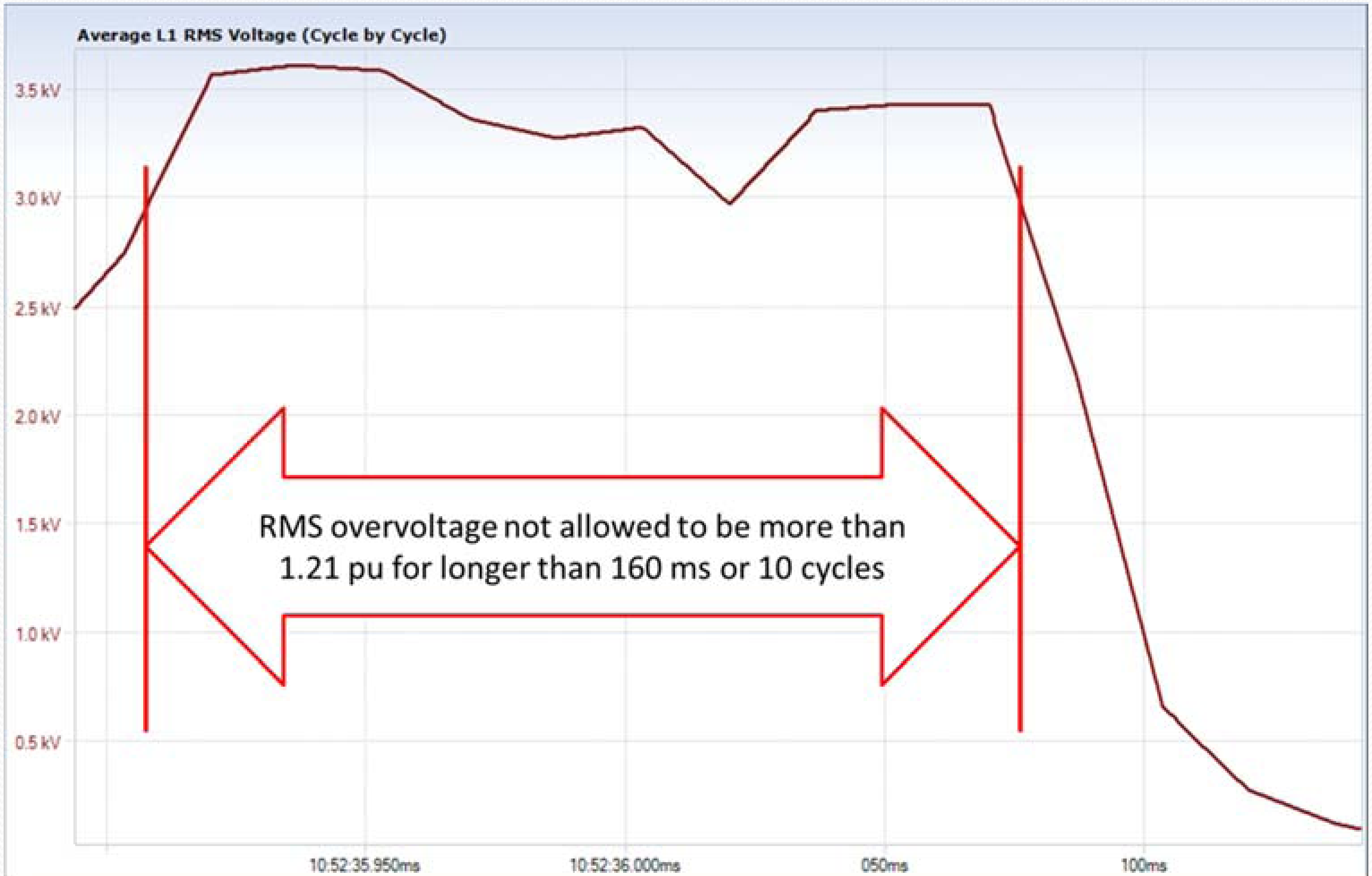
Three Phase Disconnect Test

- Three phase disconnect over voltages can be damaging to equipment and customers on the Distribution System
- The worst case for over voltages is when disconnecting the inverters at maximum output and leaving no load connected to the inverters after the disconnect takes place
- Due to solar system limitations PV facilities are required to produce 85% or higher output during the three phase disconnect test

Example Three-Phase Disconnect Test



Overvoltage Amplitude And Duration



Lessons Learned

- Most overvoltage conditions seem to be as a result of long underground AC cables between the inverter and the transformer connecting to distribution feeder causing some ringing effect.
- Large inverters more often have overvoltage issues than multiple small inverters or string inverters.
- The same inverters used in the same design with the same type of interconnection transformer, voltages and grounding systems have shown to produce different over voltages. It has become clear that over voltages seem to be unpredictable and must be tested per installation.

Customer Equipment Failure

- It was noticed that customer equipment failure was most likely to occur during the first few days of maximum output. It has therefor become practice to have the facility produce power for seven days before a witness test is attempted. During that time, no energized work on the feeder will be allowed until the disconnect switch to the facility has been opened and locked out.

Radio Frequency Interference

- Radio Frequency Interference can sometimes be detected due to the production of power using some inverter systems. A simple handheld AM band radio suffices to detect when the inverter(s) are causing RFI. The RFI increases as power production increases but never goes completely away until the inverter(s) shut down.

Conclusions

- This paper discussed challenges faced and lessons learned when integrating distributed generation, in particular exporting photovoltaic solar installations.
- Challenges discussed are related to protection, modeling, communications and synchronization.
- Lessons learned from field installations suggest specific test setups and procedures to prevent undesirable behaviors during operation.
- Given these complexities no ‘one fits all’ solution exists, and each case and application require individual analysis for selecting the best solution.
- For further enhancements leading to maturity of this technology collective industry-wide knowledge exchange is highly encouraged.