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Subharmonic Power Line Carrier (PLC) Based Island Detection

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Abstract

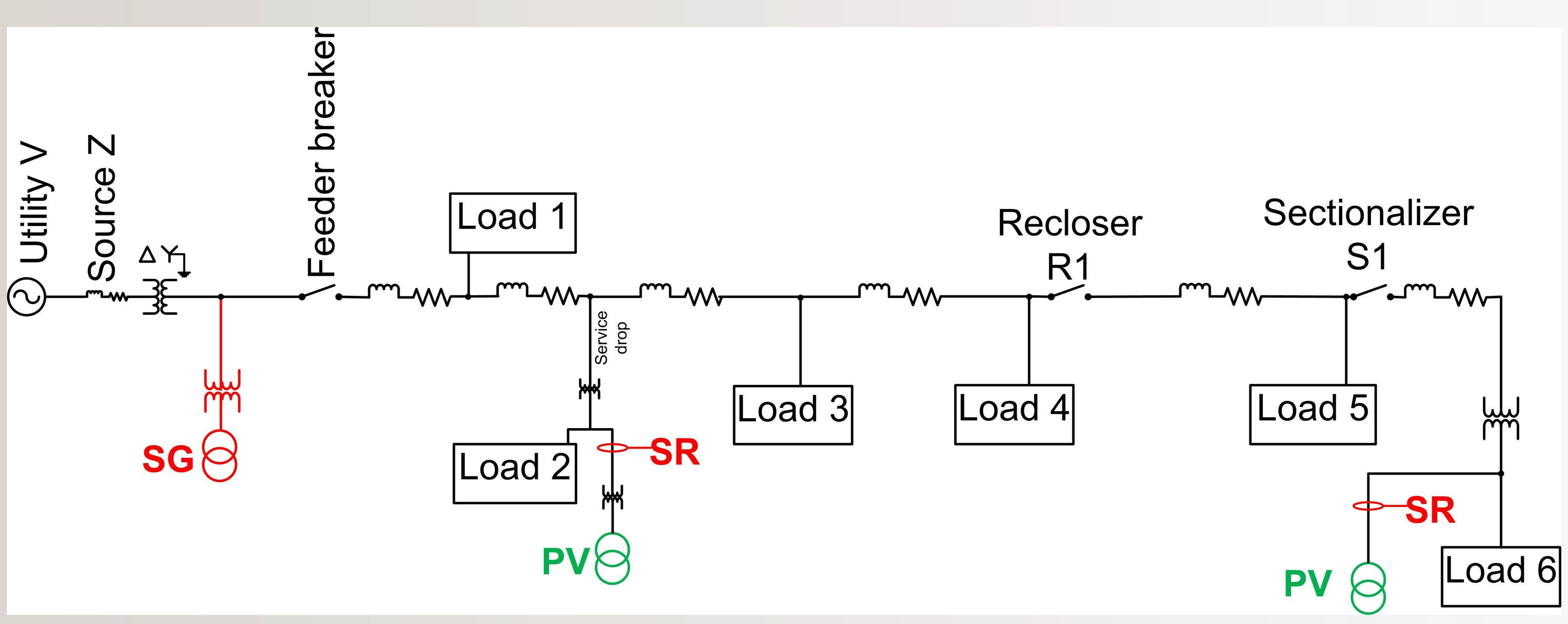
The anticipated high penetration of distributed photovoltaic (PV) energy sources is expected to lead to significant changes in utility interconnection requirements for PV systems. These changes will include provisions for voltage and frequency regulation capability, as well as better voltage and frequency ride through requirements. For distributed energy resources (DER), in particular PV, to provide grid support, it must participate in frequency and voltage regulation. Frequency and voltage ride through allows inverters to remain connected to ensure robust recovery in the event of voltage and frequency disturbance. Implementing these advanced capabilities is essential to mitigating the negative impacts of high penetration PV, but their integration into a typical distribution system presents significant technical challenges, including increased risk of unintentional islanding.

In this work, an island detection method is presented that relies on a continuous subharmonic signal, a power line carrier permissive (PLCP), that is injected at the transmission level or at the substation and detected by any type of DERs in any combination. Absence of the signal indicates loss of utility and possible island condition.

The Power Line Carrier (PLC) – Two Methods

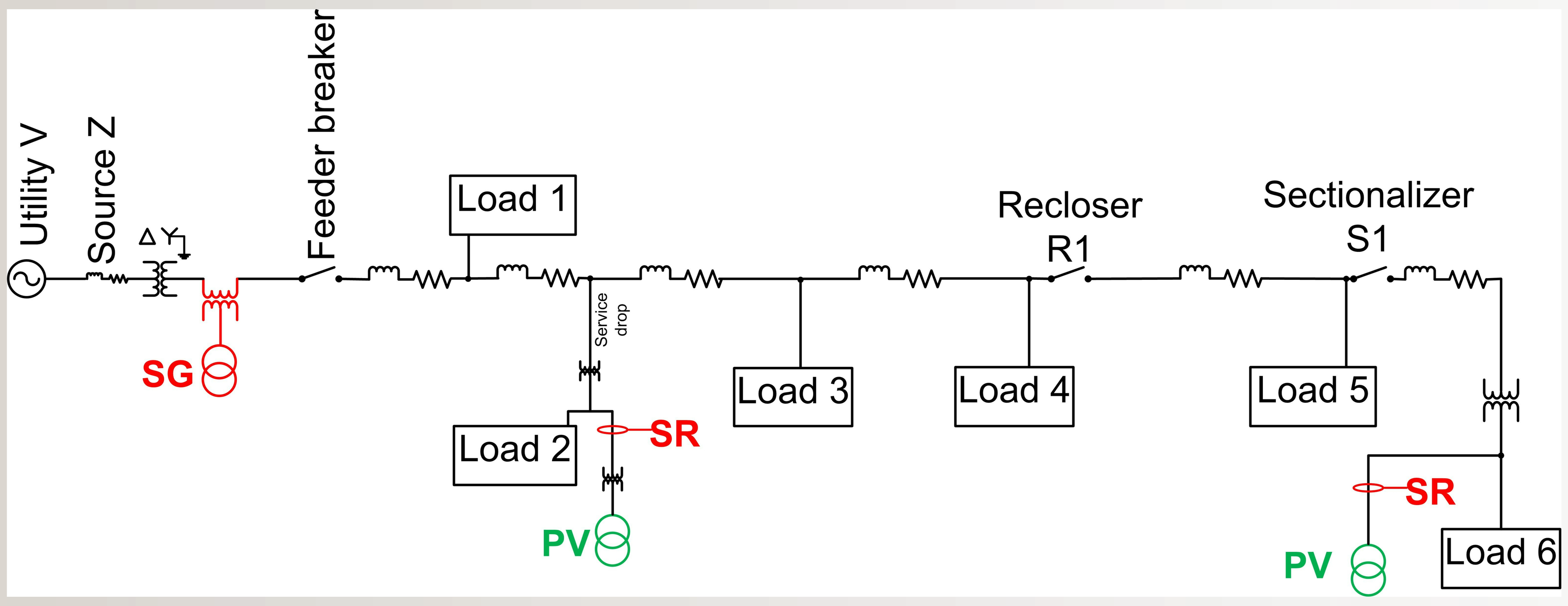
Shunt-Current Signal Injection

Consider a generic distribution feeder which includes feeder segment impedances, loads, two PV plants (shown in green), and a PLC signal generator (SG) shown in red at the left that is paired with two PLC signal receivers (SR), one at each PV plant, also shown in red. The most common way of creating the subharmonic signal is to short the SG transformer secondary to ground periodically, usually close to the zero crossing of the voltage waveform to minimize current.



Series-Voltage Signal Injection

The technique proposed in this work uses what is effectively a low-power dynamic voltage restorer as the signal generator. This technique uses a series injection transformer in which the transformer secondary is in series with the distribution feeder. The SG itself is an inverter that produces the subharmonic waveform to be injected. This system provides flexibility in that the injected harmonic can have any frequency or waveform desired as long as such production does not result in excessive currents in the inverter or a violation of flicker standards. In addition, the magnetic components of the proposed system are expected to be significantly smaller than those used in current shunt injection based approaches.

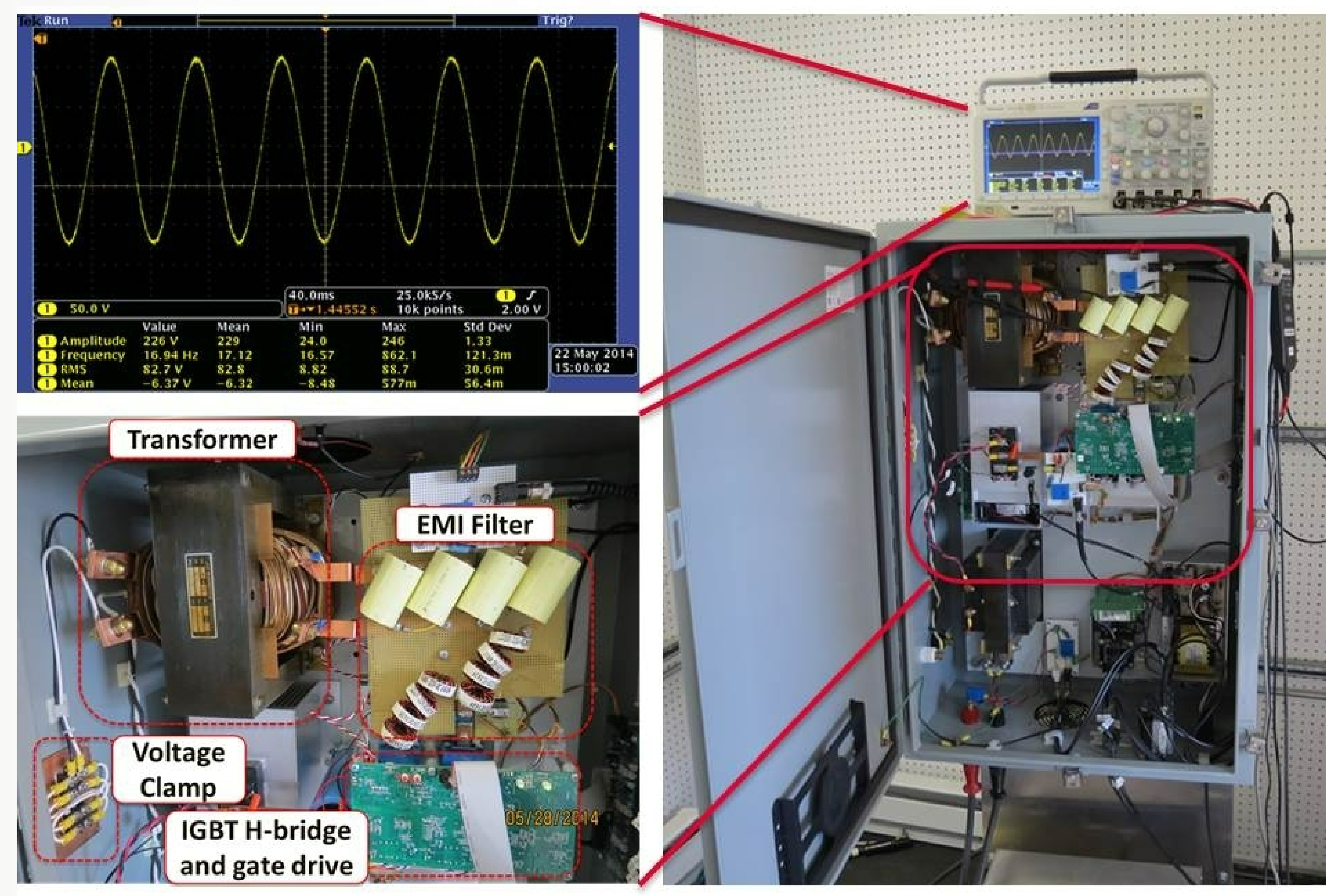


The Power Line Carrier (PLC) Laboratory Hardware

A test circuit was configured to mimic a distribution circuit with grid connection, transformers, cabling, load and PV source.

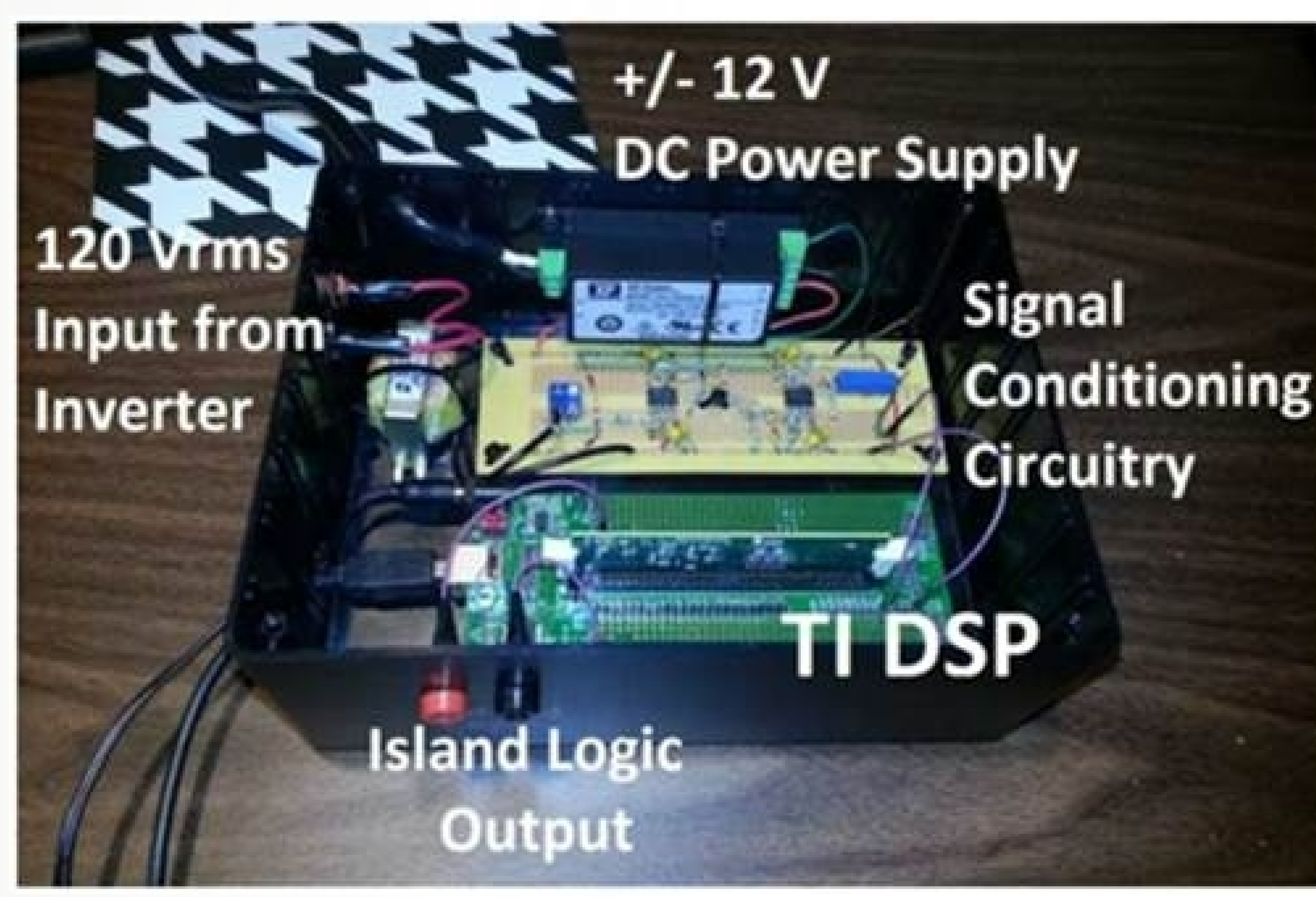
Signal Transmitter

The subharmonic transmitter was realized using a custom built voltage source inverter (VSI) coupled to the a-phase of the grid simulator through a 43:1 step-down series injection transformer.



Signal Receiver

The receiver was implemented using signal conditioning circuitry and a Texas Instruments digital signal processor (TI TMS320F28335 DSP). The receiver indicates an island condition through a digital logic output.



The PLCP receiver signal conditioning circuitry included a 120:5 V_{RMS} step down transformer, an active 5th Order Chebyshev filter, and a gain and level shifting circuit. The Chebyshev filter served as an anti-aliasing filter and reduced the magnitude of the 60 Hz element by roughly half to provide more dynamic range. The gain and level shifter circuit reduced the amplitude of the waveform and applied a DC offset to satisfy ADC input requirements. The conditioned signal was then fed to the DSP.

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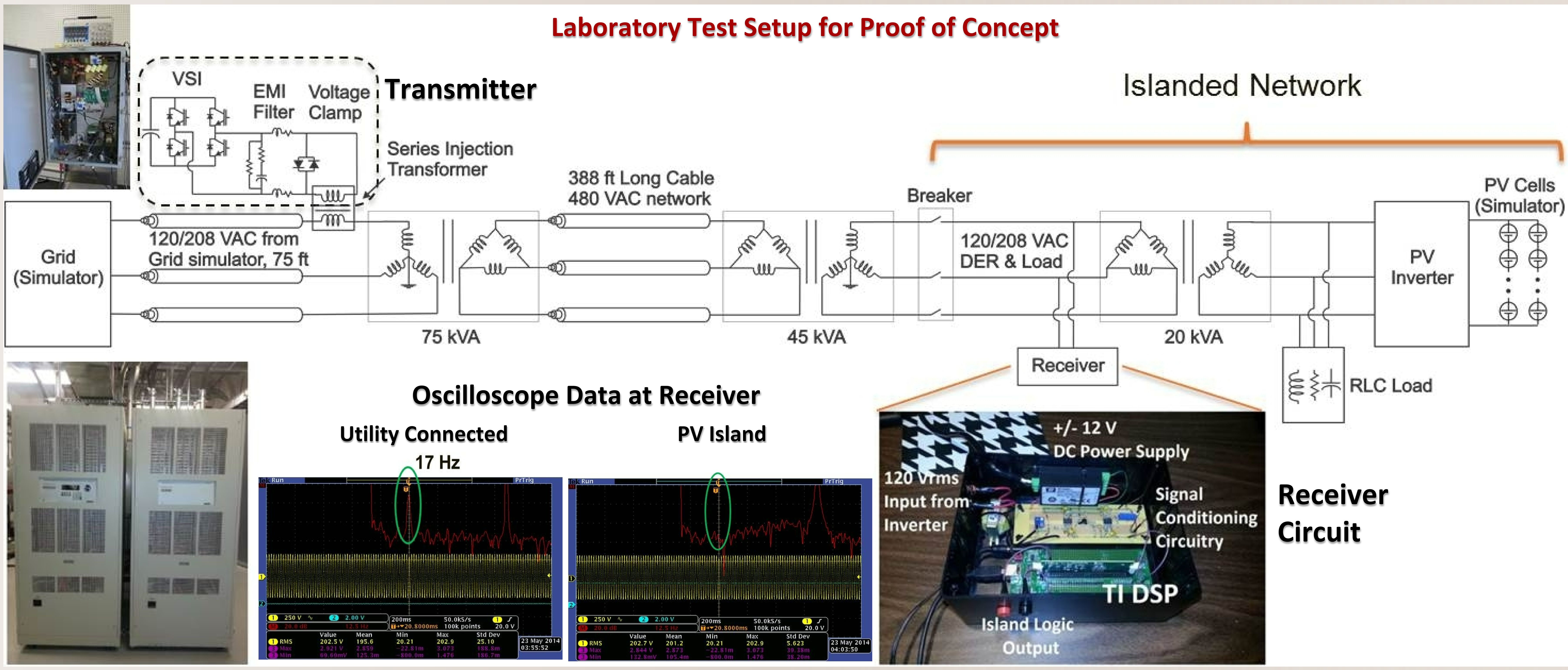
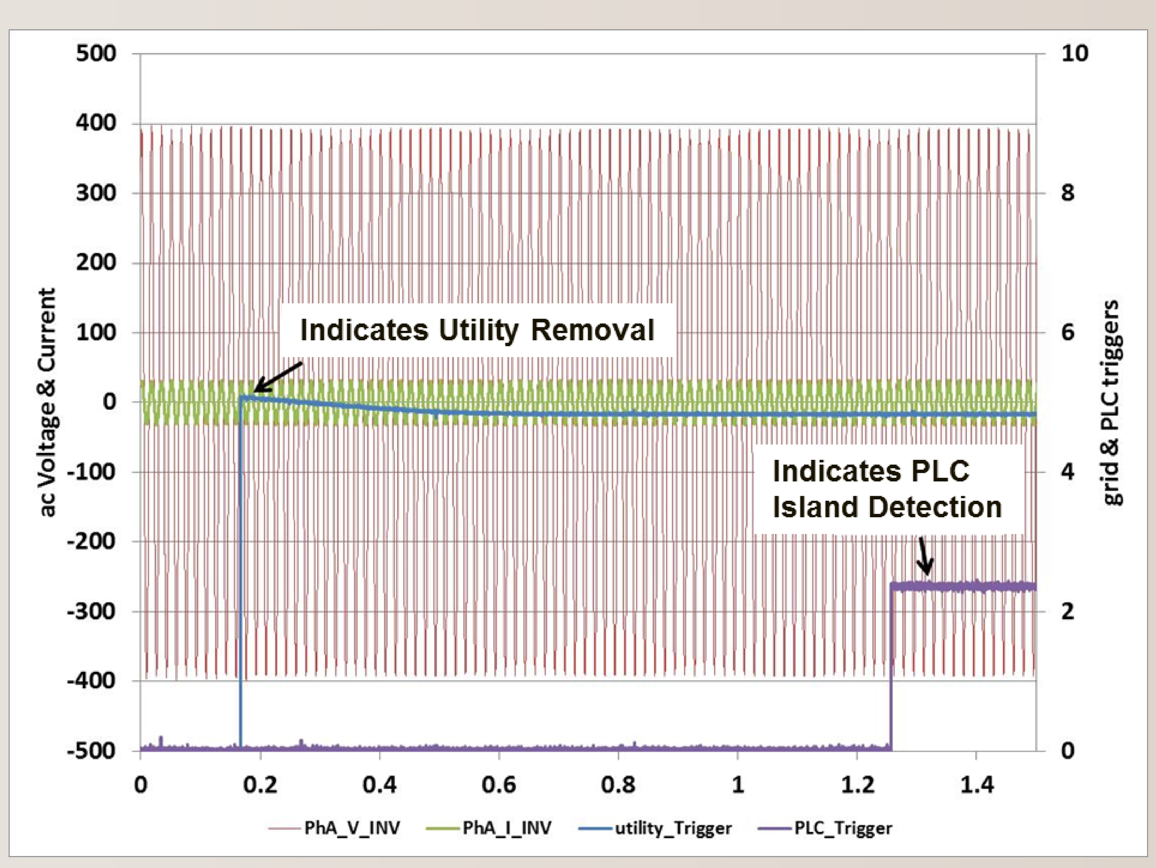
Laboratory Test Setup for Proof of Concept



Laboratory Test Results

The PV inverter and emulator were configured to deliver approximately 17 kW, and the inverter's voltage and frequency ride through limits were increased. The RLC load used for islanding tests was configured for both real and reactive power match and a quality factor of 1. The inverter was configured such that the system islanded when the breakers were opened. The 17 Hz signal is nearly imperceptible in the time-domain voltage (yellow trace above) but clearly present in the fast Fourier transform (FFT – red trace above) of the voltage.

Detection times were measured by monitoring the utility disconnection relay signal and receiver logic output (tiel and purple traces to the right respectively)

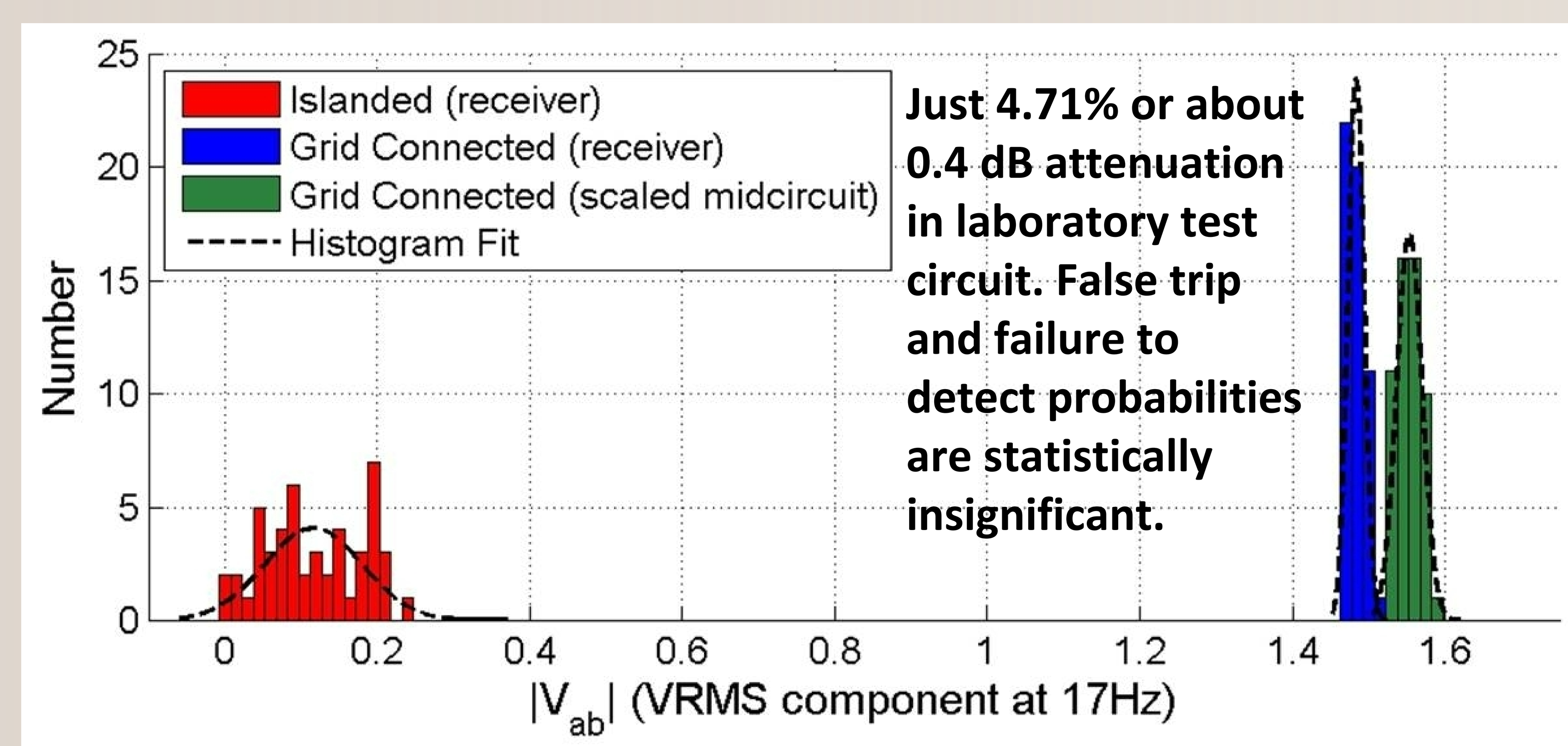


Two detection Algorithms, #1 and #2, were evaluated for their islanding detection effectiveness and speed. Test results are shown in the Table.

Algorithm 1 detected more quickly than Algorithm #2, largely because an averaging window was used in Algorithm #2; however, both approaches were compliant with the 2 second unintentional island detection requirement stated in the IEEE 1547 standard.

Test	Q factor	Pg/Pl ratio	PLC detection (seconds)
Algorithm 1 (raw signal)			
1	1	1	.386
2	1	1	.372
3	1	1	.338
4	1	1	.455
5	1	1	.418
Algorithm 2 (5 & 100ms averaging window)			
6	1	1	.574 (5ms)
7	1	1	.807 (5ms)
8	1	1	1.08
9	1	1	1.08
10	1	1	1.08

The dynamics of the PV inverter will naturally introduce some low frequency perturbations, and the measured 17 Hz component is thus expected to vary slightly. This raises concerns of false trip immunity. To test the PLCP signal integrity and attenuation, line-to-line voltages were sampled in the islanded and grid-connected (grid simulator) modes of operation. The magnitude of the 17 Hz component in each case was evaluated statistically by fitting the data to a normal distribution.



CONCLUSIONS

A new subharmonic power line carrier (PLC) based island detection scheme has been developed, and its feasibility has been demonstrated. Experiments were conducted on a laboratory circuit that was designed to mimic a generic medium voltage network with a PV source. The receiver implementation was evaluated using different algorithms and shown to comply with 1547 standards. The main advantage of the proposed method over previously deployed shunt current injection methods is an expected reduction in the size of the transformer that must be installed at the substation.

The primary design constraint is given by the IEEE 1453-2004 flicker standard. Guidelines are given for limits on the sinusoidal 17 Hz signal when considered alone. However, in practice, application of the flicker standard will be site specific. Since all signals contributing to flicker response must be considered together for compliance, a strong presence of other signals contributing to lamp flicker may indirectly limit the permissive signal further.

ACKNOWLEDGEMENTS

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