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Subharmonic Power Line Carrier (PLC) Based Island Detection

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, one of which is the increased risk of unintentional islanding. In this paper, 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 types of DERs in any combination. Absence of the signal indicates loss of utility and a possible island condition. Preliminary laboratory tests were done to investigate feasibility of the method. The PLCP system discussed here is novel in that it utilizes a power electronics based series voltage injection method, an approach that offers unique advantages.

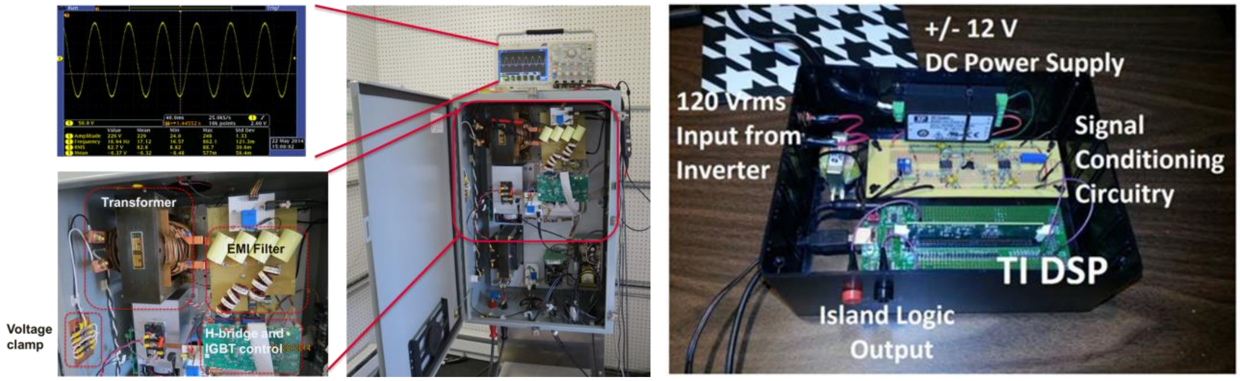
INTRODUCTION

As more distributed renewable generation is incorporated into the grid, well-regulated conventional generation will be displaced by stochastic energy sources, which can have adverse effects on the power system if not managed properly [1]-[3]. It is well known that high penetrations of PV may have negative local impacts, including voltage rise, reverse power flow, power fluctuations, power factor changes, unintentional islanding, and fault currents [3], but it is now becoming clear that sufficiently high penetrations of PV can also have negative wide-area impacts. Recent studies that consider the impact of PV on low frequency inter-area modes have reported that greater PV penetration may "detrimentally effect the inter-area mode" through reduction in damping [4] or introduce the potential for new oscillatory modes [5]. Anticipating the high penetration of PV DER has thus led to significant changes in utility interconnection requirements that include voltage and frequency regulation requirements and voltage and frequency ride through requirements. These new requirements will help to avoid the aforementioned problems, but unfortunately they will increase the difficulty in detecting unintentional islanding. In this paper, a communication-based anti-islanding or unintentional island detection method is presented that relies on a Power Line Carrier Permissive (PLCP) signal that is carried between distribution/transmission components and the inverter to establish whether an island has occurred.

The novelty of the method presented herein is that it involves a subharmonic voltage being injected via a series injection transformer in series with one or more phases. A subharmonic permissive signal can pass through power transformers, will propagate over many miles of transmission line with little attenuation, and is less susceptible to interference from active loads. Since the method proposed here involves series voltage injection, the magnetic components of the system will be significantly smaller than those used in current shunt injection based approaches such as the method based on that used for automatic meter reading [7]. One concern with the subharmonic PLC in general is with maintaining compliance with the IEEE 1453-2004 flicker standard [8]. The largest possible value of a 17 Hz signal should be used to maximize signal to noise ratio (SNR), but the upper limit is constrained by flicker limits. In this digest, that subharmonic limit is quantified, and preliminary hardware tests are presented.

OVERVIEW OF PLC LABORATORY HARDWARE

To test the subharmonic PLC approach and the viability of the series injection scheme, a laboratory test was devised and test hardware was fabricated; see Figure 1. The grid connection was emulated using a power electronics based grid simulator. The subharmonic transmitter was realized using a custom built voltage source inverter (VSI) coupled to the a-phase of the grid simulator through a step-down series injection transformer. The grid simulator was connected through three transformers, 100’s of feet of cable and a breaker to a commercial inverter configured for islanding tests. The direct current (dc) source for the inverter was a power electronics based PV emulator; see Figure 2. The receiver was implemented using a Texas Instruments digital signal processor (TI DSP) that executed FFT and DFT-based signal detection algorithms.



(a) (b)

Figure 1: Shows (a) subharmonic PLCP transmitter and (b) receiver hardware

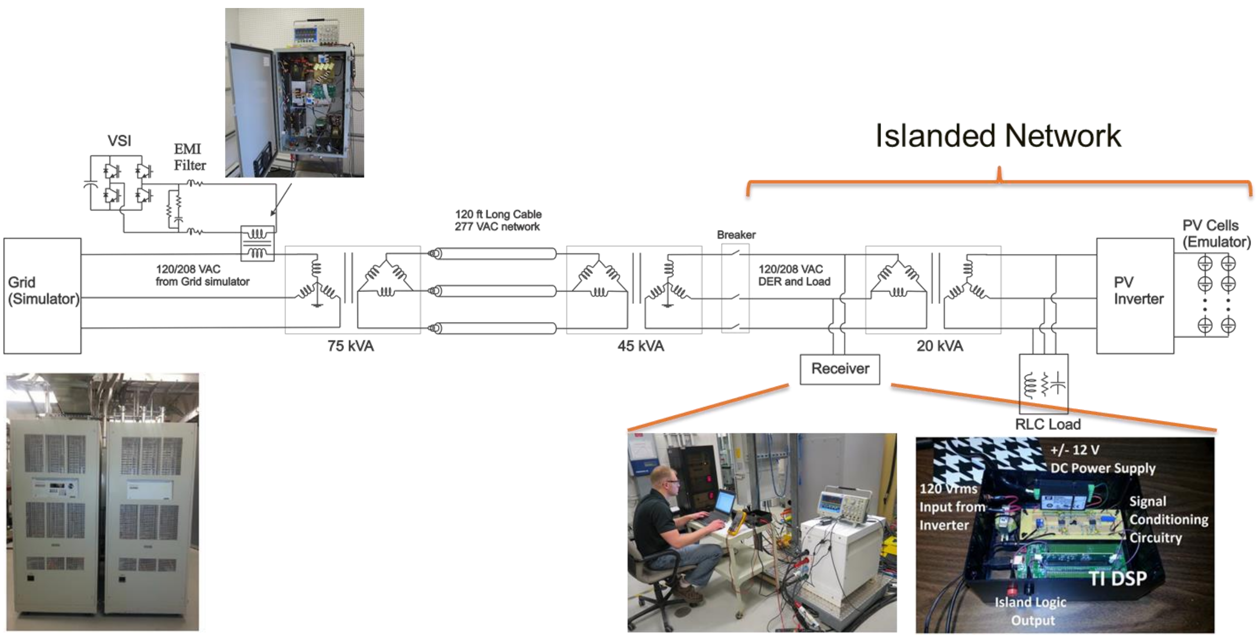
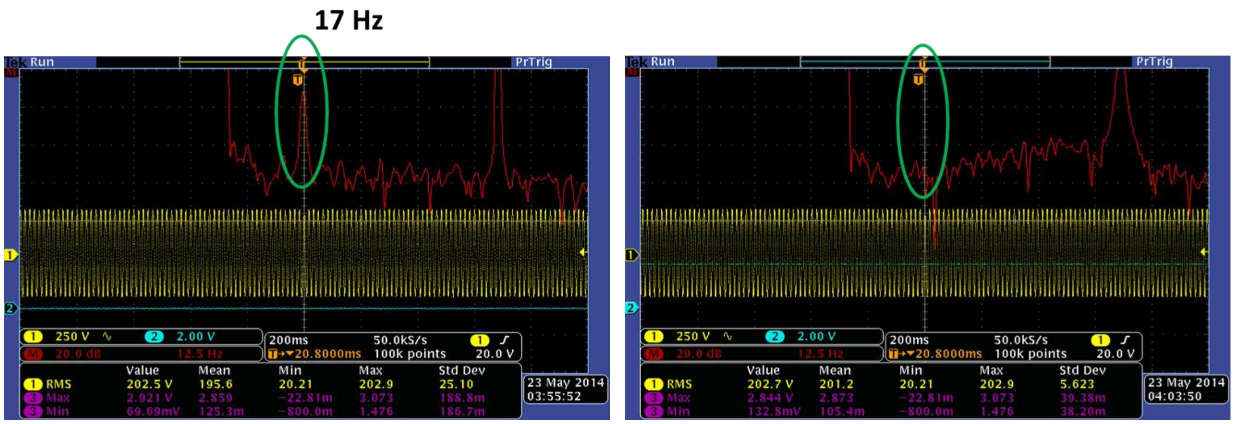


Figure 2: Laboratory setup for PLC proof of concept testing

PRELIMINARY TEST RESULTS

The grid simulator was configured as a 121/208V 60 Hz Wye voltage source, and the subharmonic transmitter was configured to inject 1.9V RMS voltage at 17 Hz in series with the a-phase of the grid simulator. Preliminary calculations suggested that the 1.9 V RMS signal would provide sufficient SNR for the selected hardware, and using a MATLAB flickermeter block, it was determined that the short-term flicker parameter Pst resulting from the injection of this signal would be 0.37, which should not lead to flicker problems [8]. 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. Despite the use of active anti-islanding, the system islanded when the breakers were opened. Figure 3 shows the line-to-line voltage as measured by an oscilloscope at the receiver location for both the connected and islanded cases. The 17 Hz signal is nearly imperceptible in the time-domain voltage (yellow trace) but clearly present in the fast Fourier transform (FFT – red trace) of the voltage.



(a) (b)

Figure 3: Line-to-Line voltage shown in time and frequency domain, measured at receiver location in circuit for (a) connected and (b) islanding

Two algorithms, both based on discrete-time forms of the Fourier transform, were investigated for quickly discerning the presence of the subharmonic signal. Herein, we designate these as Algorithm 1 and Algorithm 2 for brevity. More detail is given in the final manuscript. Each algorithm was tested five times, and the time to detect was recorded; this is equivalent to run-on time. The results are shown in Table 1. Algorithm 1 detected more quickly than Algorithm 2, but both approaches were compliant with the 2 second unintentional island detection requirement stated in the IEEE 1547 standard.

CONCLUSIONS and FUTURE WORK

A new subharmonic power line carrier (PLC) based island detection scheme has been developed, and its feasibility has been demonstrated in the laboratory. In the final manuscript, greater detail will be provided about the hardware test setup, the benefits of series injection, the limits on transmission voltage computed for IEEE 1453-2004 flicker standard compliance and about each of the algorithms used.

Table 1: Results of Islanding Tests for Both Algorithms

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

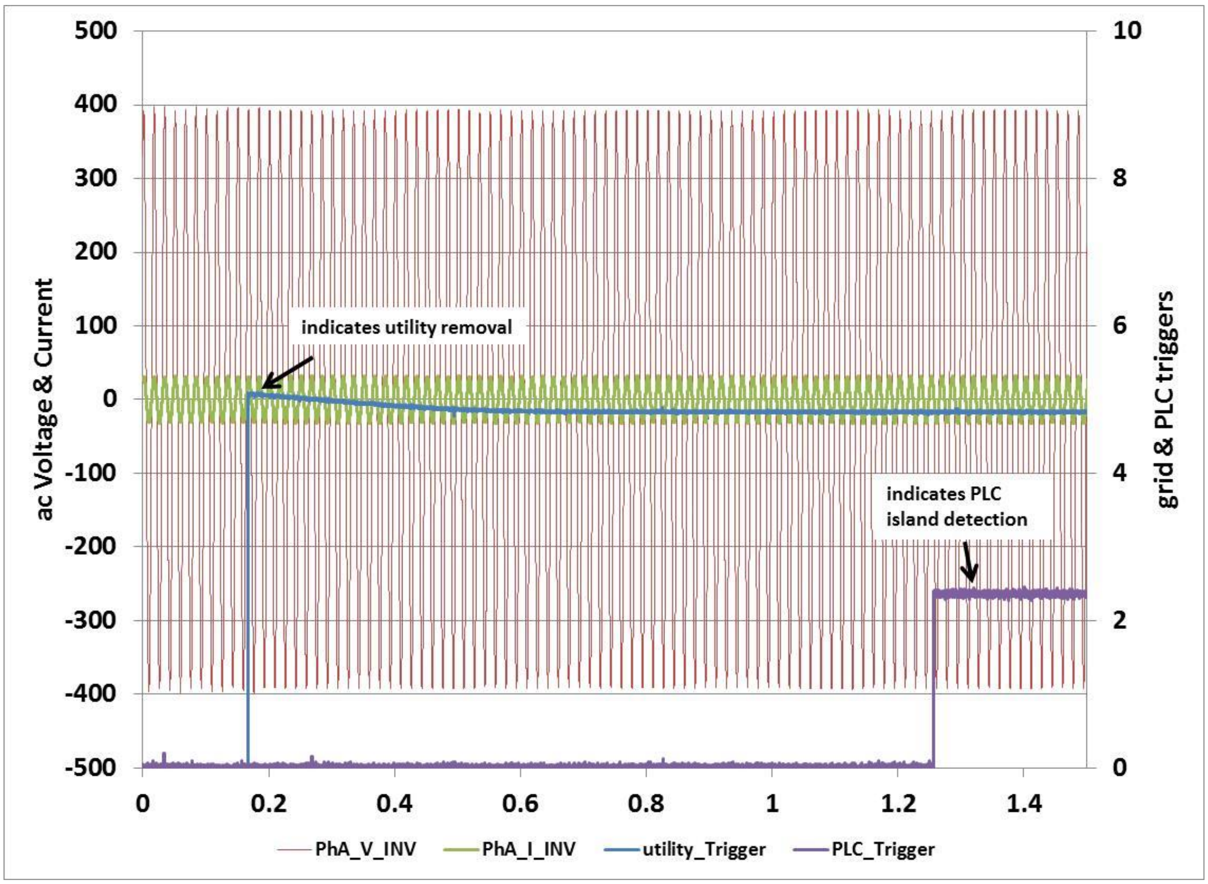


Figure 4: Waveforms from islanding test 8 showing AC line voltage, signal indicating utility removal and signal indicating island detection

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