Grid loss protection for Solar – Wind Hybrid based Utility interactive inverter

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***Abstract*— Anti-islanding protection is very important for modern inverters connected to utility. India is a fast growing economy with raising energy consumption through renewables having a target of 175 GW by 2020. This paper describes the anti-islanding protection function in a 20 kW solar-wind hybrid inverter with battery backup option considering only the solar input side connected at input and utility connected at output side. As per the Indian standard 16169 which was released in 2014, any power conditioning unit connected to utility must disconnect from utility within 2s after it goes off-line. The three different voltage levels and total of 31 conditions were simulated for various real and reactive power maintaining quality factor 1 at utility side through a 200 kW RLC load and the disconnection time of inverter were obtained through a high definition oscilloscope. For the inverter tested for anti-islanding protection function, it was found that in all scenarios the inverters disconnection time was well within two seconds as per the limit imposed by IS 16169:2014.**

Keywords—inverter, anti-islanding, grid tied, disconnection time, hybrid, volt-var, volt-watt

I. Introduction

Unintentional islanding of distributed generation may result in power quality issues, interference with grid protection devices, equipment damage, and personnel safety hazards. A comprehensive survey of anti-islanding schemes indicates that existing solutions are too expensive (e.g., transfer trip), not secure (e.g., non-detection zone), or cause power quality degradation (waveform distortion). In an effort to positively enhance the impact of increasing amounts of distributed energy resources, grid-tied photovoltaic (PV) inverters are increasingly being designed to provide advanced grid support functions (GSF) that can provide volt-var and frequency support at their local point of interconnection. Among others, these GSFs include voltage ride-through (VRT), frequency ride-through (FRT), fixed power factor (FPF), volt-var control (VVC), and frequency-watt control (FWC) [1]. Nowadays, almost all photovoltaic and grid-connected inverters, have internal protections against islanding. Usually, these protections perform a disconnection from the grid when process variables go beyond over-voltage or under-voltage thresholds, as well as over-frequency or under-frequency thresholds. Furthermore, other schemes are often added in commercial equipment. In spite of the importance of anti-islanding protections, it is not easy to test on field thresholds, reliability and performances of these devices [2]. Islanding occurs when a distributed generation source continues to provide electricity to a portion of the utility grid after the utility experiences a disruption in service. Since the utility no longer controls this part of the distribution system, islanding can pose problems for utility personnel safety, power quality, equipment damage, and restoration of service [3]. This paper takes into account of only the grid disconnection anti-islanding protection that is incorporated in hybrid inverter.

II. Objective

A. *Objective*

The primary objective was to validate the effectiveness of anti –islanding protection function in a solar-wind hybrid inverter. Effectiveness was determined by the speed with which the inverter detects and ceases to energize the utility.

B. *Inverter Description*

The grid tied hybrid inverter is of 20 kVA with unity power factor (i.e. 20 kW) with a DC voltage range of 220 V to 280 V and 110 A current ranges at DC side. The inverter output AC side is having a voltage range of 200 V to 264 V each phase and 100A current range with frequency range of 49 to 51 Hz (as per Indian grid code). The interior and exterior view of the inverter is shown in Figure 1. Efficiency test was performed as per latest edition of IS 61683 standard on this 20 kVA hybrid inverter when connected to the utility, the efficiency was found to be 91.74 % at rated voltage, rated output and rated frequency conditions.

Figure 1: Interior and exterior view of the 20 kVA hybrid inverter

III. TEST CIRCUIT BLOCK DIAGRAM

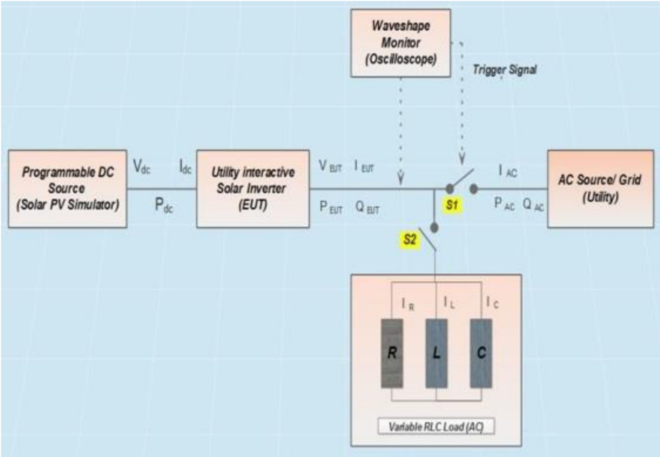

Figure 2: Test circuit diagram for anti-islanding test as per IS 16169: 2014 standard [4].

Solar DC input was provided through a solar PV array simulator for feeding DC voltage and current considering the solar PV module parameters. Inverter output is connected to 90 kVA utility system through S1 circuit breaker paralleled with 200 kW RLC load system through S2 circuit breaker. An oscilloscope is connected in parallel with S1 circuit breaker and a small DC source enough to capture a trigger signal when utility disconnects (S1 opened). A power analyzer of 4 channels capable to measures both 3 phase AC measurements and DC measurement simultaneously was used to identify the electrical parameters like voltage, current, power factor, harmonics, loss and efficiency of the inverter.

IV. TEST PROCEDURE

This test procedure was incorporated from IS 16169: 2014 standard [4].

1. Determine EUT Output Power
2. Adjust DC input source
   a. S1 closed, S2 opened
   b. Turn EUT ON, Measure EUT power output
   c. Measure real , reactive power, frequency, utility power(real and reactive)
   d. Real power = reactive power for utility
3. Turn OFF EUT and Open S1
4. Adjust RLC load to have Qf = 1 ± 0.05
   a. Inductive reactance = EUT real power
   b. Inductor as first element
   c. Adjust capacitor to have : QC + QL = - Q EUT
   d. Connect resistor to have power consumed by RLC circuit = P EUT
5. Connect RLC load as per item 4 and Close S2.
6. Close S1 and turn the EUT ON
7. Adjust RLC to have AC current to be 0 A through S1 with 1 % tolerance
8. Disconnect S1 to initiate the test.
9. Run on time , t_R to be recorded
10. For test condition A, adjust real load and only one reactive component by approximately 1 % per test within a total range of 95% to 105%.
11. If run on times are increasing, and then increase 1% increments until run on time decreases.
12. Test C load conditions may be achieved using inverter control to limit output power rather than power supply limit.

V. RESULTS

The sample tested is a 20 kW solar –wind hybrid inverter having 3 phase 4 wire system. Figure 2 shows the disconnection time of a condition in which the inverter was supplying 100% rated power i.e. 20 kW to the load and zero power were being sent to grid (balanced condition) with maintaining quality factor of 1. The disconnection time is the time from which the grid goes offline to the current zero point of inverter output. This was measured through an oscilloscope where a trigger signal is generated when the grid goes offline (indicated in blue), voltage of the inverter indication is pale yellow and current from the inverter to the grid is indicated in pink.

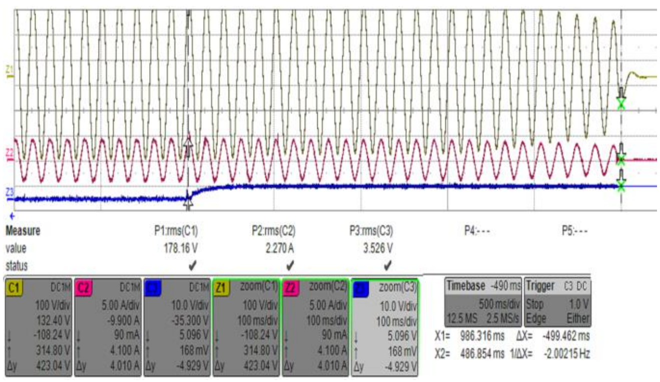

Figure 3: Test result for 100% EUT load under balance condition measured at Y-phase of a 3-phase solar-wind hybrid inverter.

Table 1: Average disconnection times under balanced and un-balanced conditions

P(EUT), %	Disconnection time (in milli-seconds)	
	Balanced Condition	Imbalanced Condition
100	499.46	637.607
66	305.73	237.336
33	396.56	207.146

The voltage measurement from the individual phase is obtained through a high voltage differential probe of 1000V and the current measurement from individual phase was captured through a current sensor of 20/200 A rating. The trigger signal is obtained from the circuit breaker linked with the utility (S1 of Figure 1) and a DC source of 5V/1A connected in parallel with both circuit breaker and oscilloscope.

As per the testing standard, the number of test conditions for balanced condition is only 3 with different voltage and power levels. For rated power output condition with imbalanced loading to grid, there are 8 conditions. For 66% and 33% rated output power with voltage level reduced to half and less than 25% of input voltage range, the imbalance conditions are 10 for each voltage levels. From Table 1: we can interpret that the disconnection time in imbalanced condition is higher than balanced condition for rated output power of the inverter and similarly the disconnection time at around half the rated output and at minimum rated output is higher for balanced condition than the imbalanced condition. It may vary for different types of inverter and may not be applicable to all inverter categories. This disconnection time depends on the circuit design and the topology used for synchronization with utility. The maximum disconnection of 637.607 milli-seconds (ms) is observed and the minimum disconnection tie observed is 207.146 ms. The disconnection times provided in the Table 1 is averaged for all three phases, also the disconnection time with real and reactive power variation conditions were averaged.

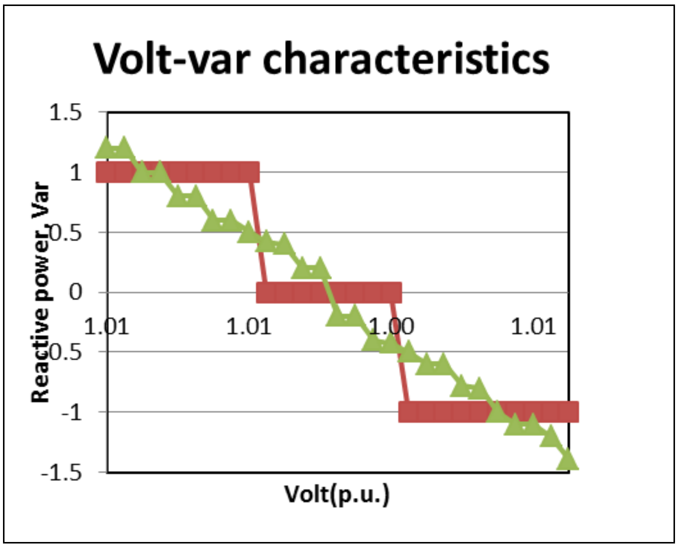

Figure 4: Volt- var chracteristics of 20 kW hybrid inverter

Three different test voltage conditions were used as per the standard with respect to different power output levels. The voltage levels obtained were 220V, 222 V and 224 V for 100%, 66% and 33% output power levels respectively.
A 200 kW RLC load was used for varying the real and reactive power conditions as required by the standard for testing the grid functionality of this inverter.

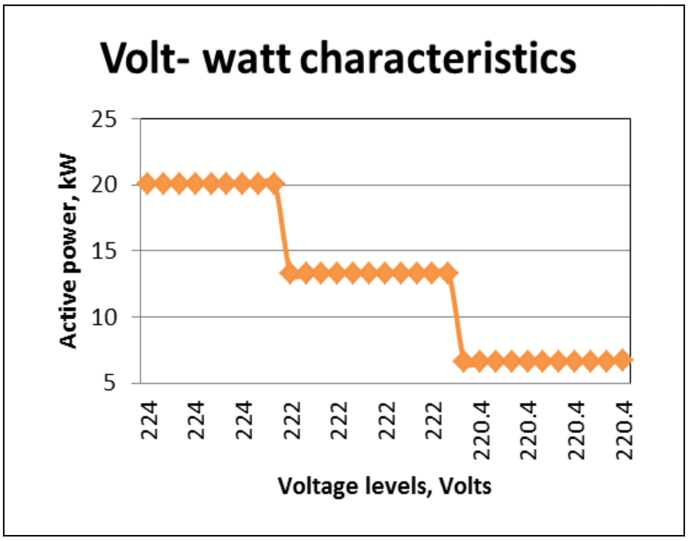

Figure 5: Volt- watt chracteristics of 20 kW hybrid inverter

The volt-var characteristic shown in Figure 4 indicates that the reactive power changes with change in voltage levels. Ideally the reactive power should be constant with same voltage (red colour), but from the Figure 2, the reactive power is reducing even as the voltage level remained same (green colour). The volt –watt characteristics as shown in Figure 5 are easily obtained for all inverters as the resistance does not vary much with reactive power variations, but varies a little (negligible) because of the practical inductance(inductance and coil resistance) and the practical capacitance (capacitance and resistance component) being used in this testing.

VI. CONCLUSION

The in-field test of anti-islanding protections for solar PV inverters can be considered as a practicable task because experiences carried out by CPRI have showed this possibility. Analysis were performed on the 20 kVA solar-wind hybrid based grid tied inverter for balanced and un-balanced load condition and identified the maximum and minimum disconnection times when connected to utility for various voltage levels. Solar DC input was provided through a solar PV array simulator for feeding DC voltage and current considering the solar pv module parameters. For the inverter tested for anti-islanding protection function, it was found that in all scenarios obtained by using a 200 kW RLC load system for different real and reactive power flow conditions the inverter disconnected well within 2 seconds as per the limit imposed by IS 16169:2014. Maximum and minimum disconnection times are 637 and 207 milli-seconds. In spite of the objective, the inverter here presented was used in CPRI's grid tied inverter test laboratory in order to perform tests under real-time simulated conditions. First results are encouraging and they indicate the importance of further improvement. Unquestionably, the increasing photovoltaic market in India increases the importance of this test.

VII. RECOMMENDATION

The anti-islanding tests at the CPRI laboratory were carried out to evaluate the effectiveness of an interconnection system and anti-islanding protection function based on IS 16169 requirements. Tripping time was used to determine the effectiveness of the protection function. Although testing could show whether protection function was effective, more fine-tuned tests are necessary to find the maximum tripping time under each condition and the correlation between parameters and tripping time. Although IS 16169 allows for alternative testing procedures, the procedures used for this study should be further for parallel connection of various DER's or multi inverter scenarios.

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BIOGRAPHICAL INFORMATION

K. Jeykishan Kumar was born in Tirunelveli, Tamilnadu, India on 15th March 1992. He received his B.Tech degree in Electrical and electronics engineering from National Institute of Technology, Tiruchirappali in 2013 and joined Ingersoll Rand after his graduation. He joined as an innovation tech lead and worked till 2014 under product lifecycle management team.

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