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Fault Current Experimental Results of Photovoltaic Inverters Operating with Grid-Support Functionality

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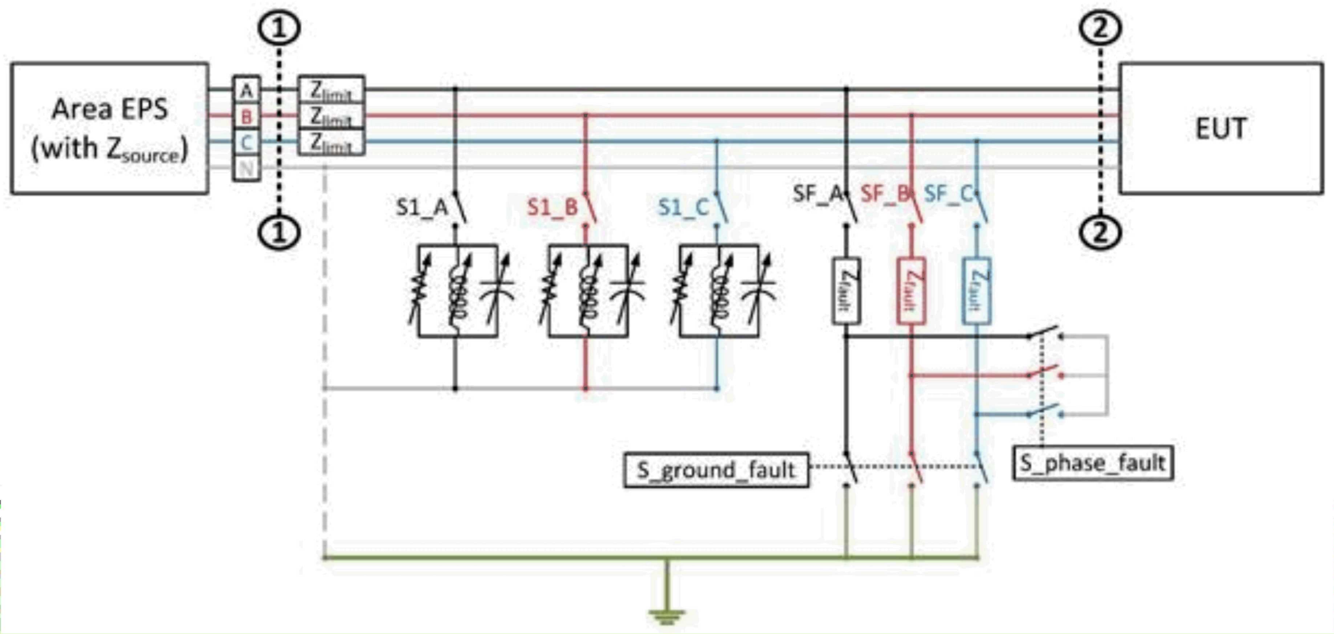
BACKGROUND

With the Electrical power system designed for power to flow in one direction, the high penetration of PV-based Distributed Energy Resources (DER) has created concerns of grid reliability and protection scheme efficacy. This paper performs laboratory tests to quantify the fault currents of three-phase and single-phase inverters under a range of grid-support function operating modes. The results characterize the PV DER sub-transient, transient, and steady-state equivalents.

OBJECTIVES

To sustain a high level of PV DER installations, voltage/frequency ride-through and voltage and frequency regulation functions are required minimize adverse effects of a high level of intermittent generation. These significant changes in modes of operation have increased the uncertainty of how the PV inverter performs during fault conditions and how much fault current an inverter contributes when operating with voltage and frequency ride-through capabilities and voltage and frequency regulating functions enabled. Two test configurations can be utilized to determine the short circuit contributions, one utilizes the utility and the other utilizes an AC simulator, which is simple to apply and provides the necessary voltage conditions at the terminals of the device under test. The two figures below are similar to the one in draft IEEE P1547.1 test procedure.



AC Simulator-based short-circuit test circuit
(used for these test results)

- The ac simulator must be sized so that the current, voltage, or power limits are ever reached during short-circuit test
- The ac simulator must regulate line-ground and line-line voltages at the terminals of the EUT (location a) to ≤ 5% of nominal voltage.

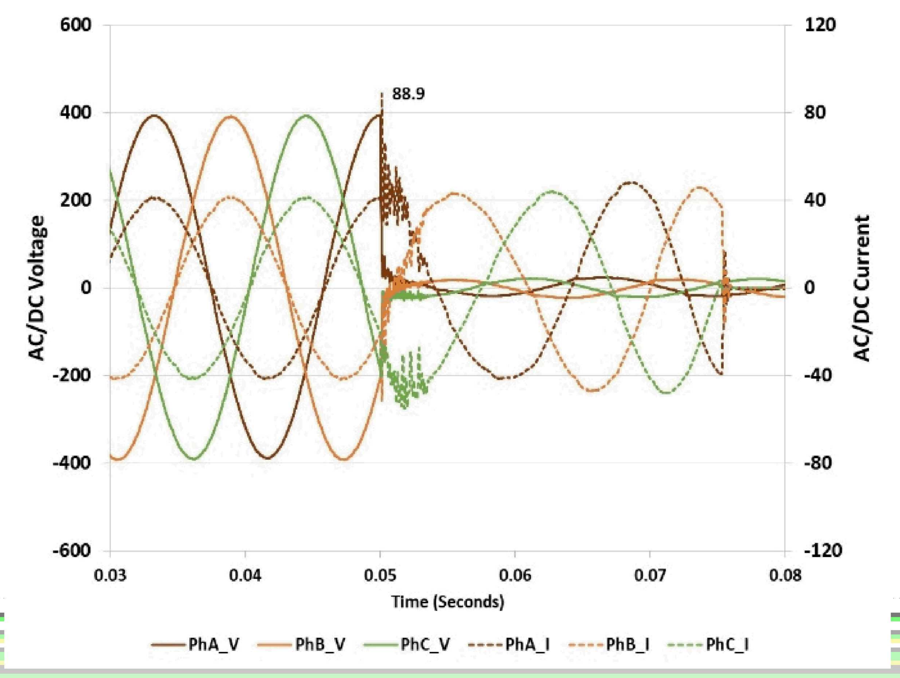
RESULTS

Laboratory evaluations indicate during faults, inverter-based DER experience a very short "transient" current spike (2 to 3 p.u.), followed by a short duration of slightly higher than rated currents (~1.1 p.u.), lasting only the duration allowed for momentary cessation requirements(<8.3ms). The table below shows the results of different types of faults and different types of inverters and the data shows the transient magnitude and the fault current duration.

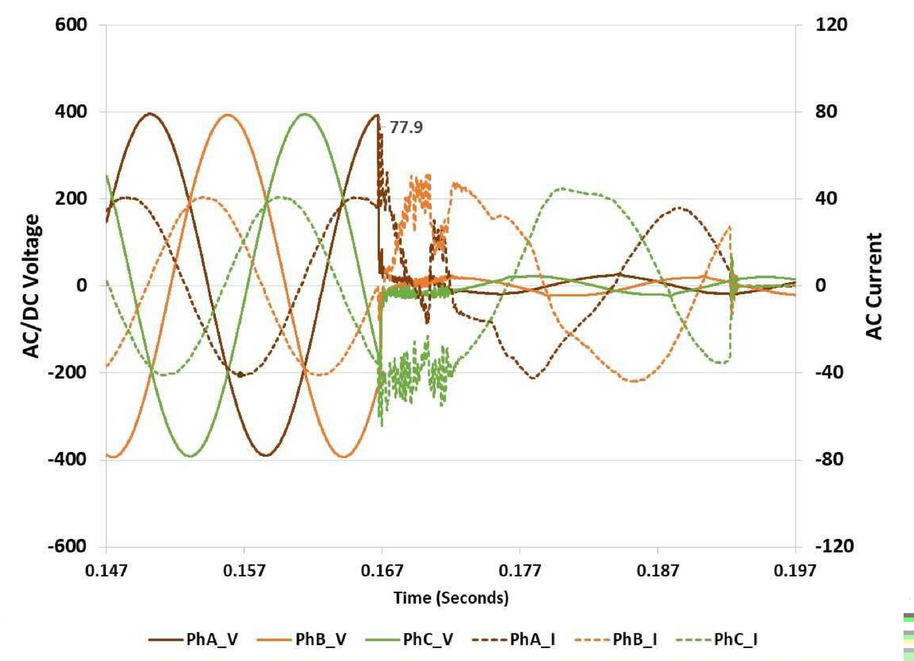
Short Circuit Fault Results of utility interconnected inverters

Inverter Operating mode	3-Phase Inverter Transient PU/Duration of Steady-State Fault (cycles)			1-Phase Inverter Transient PU/Duration of Steady-State Fault (cycles)	1-Phase ESS Inverter Transient PU/Duration of Steady-State Fault (cycles)
Types of Faults	1LG	3LG	LLG	LLG	LLG
Rated power, Unity power factor	1.9/1.49	1.9/1.52	2.1/1.54	2.3/1.75	2.2/0.65
Rated power, minimum overexcited power factor	1.8/1.50	1.83/1.51	1.9/1.50	2.1/1.73	N/A
Rated Power, minimum underexcited power factor	1.8/1.49	1.58/1.53	1.8/1.48	2.1/1.8	N/A

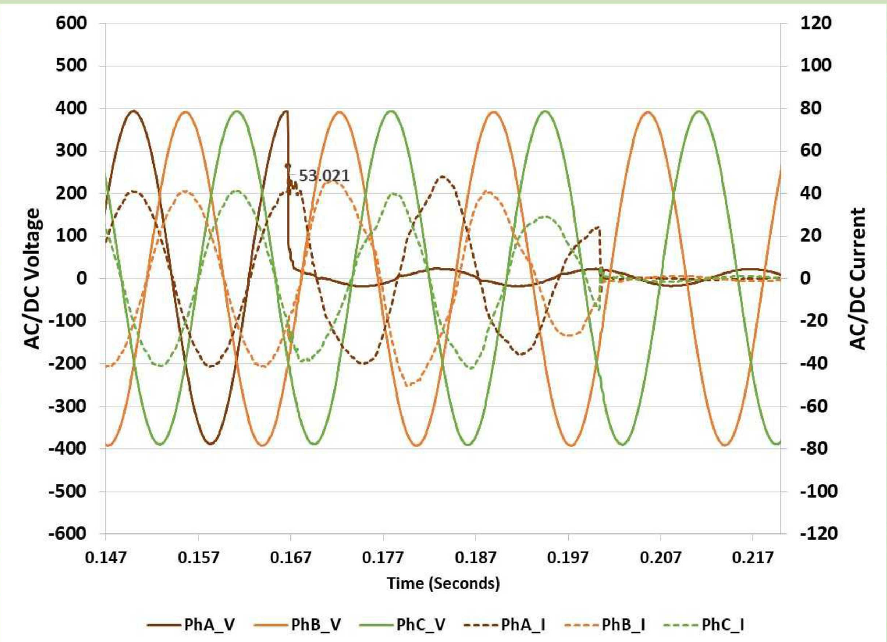
3-phase inverter short circuit and single-phase current Waveform Results



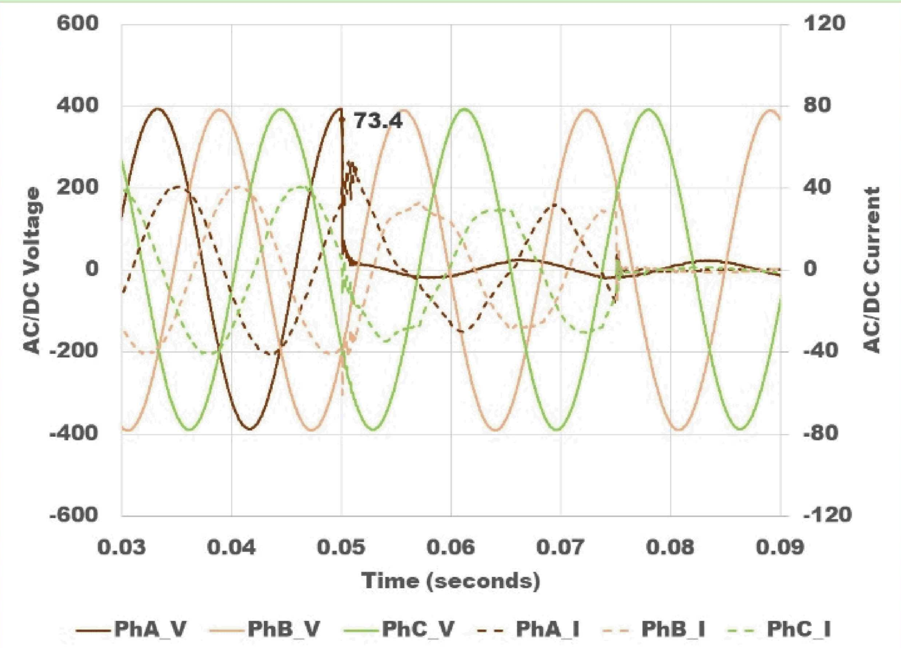
Three-phase inverter operating at rated power and unity power factor and fault current test has 95% voltage sag at 90° on phase A



Three-phase inverter operating at rated power and 0.8 power factor and fault current test has 95% voltage sag at 90° on phase A



Three-phase inverter operating at rated power and unity power factor an asymmetrical fault current test has 95% voltage sag on phase A only and initiates at 90° on phase A



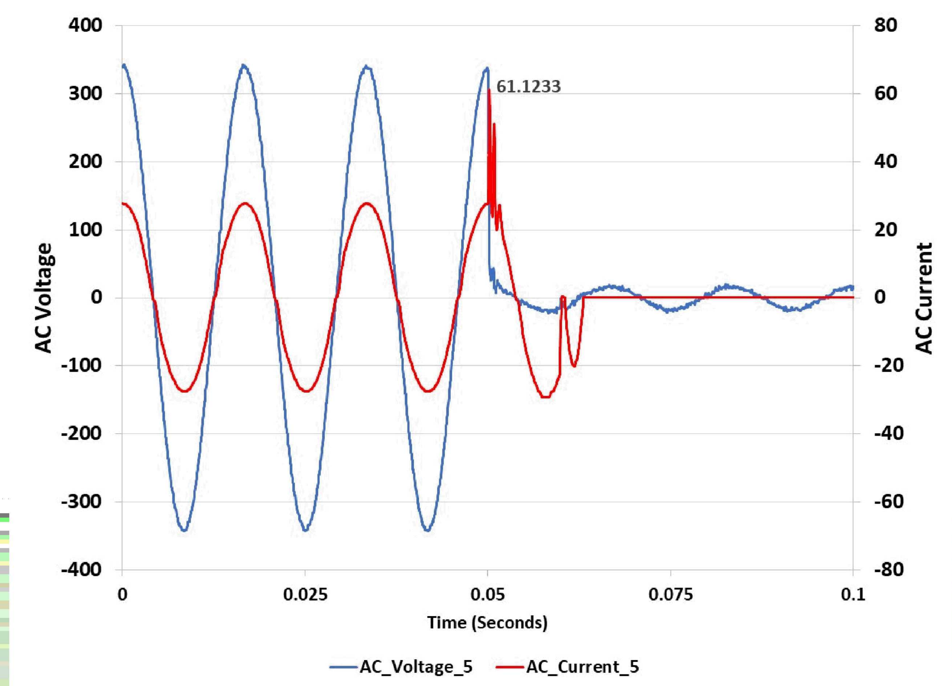
Three-phase inverter operating at rated power and 0.8 power factor an asymmetrical fault current test has 95% voltage sag on phase A only and initiates at 90° on phase A

INVERTER TRANSIENT PROTECTION ANALYSIS

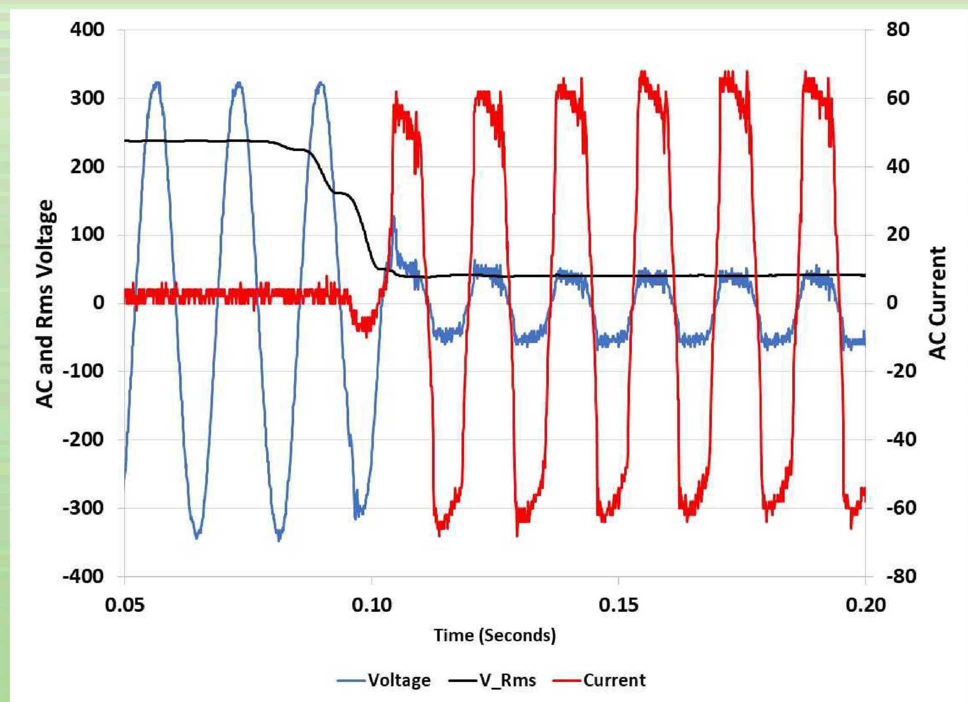
Determining the fault current contribution from an inverter-based DER is difficult because there are few references showing transient fault currents. Implementing and proper coordination of protection equipment needed to mitigate and protect against these transients are typically not necessary because the duration of the transient is short, therefore utilizing traditional protection equipment will not suffice and if protecting against this type of transient is deemed necessary, it will require specialty equipment if at all possible.

CONCLUSION

The short circuit evaluations conducted on the inverters provides documentation of the short circuit contributions from the inverters under different operating conditions and validates the method used to conduct the short circuit study. The short circuit current transients provides little energy and will not trigger fault current protection devices nor does it cause a voltage surge that could trigger surge protection schemes. These test show a maximum 1.1 p.u. steady-state current that can last up to 83ms per interconnection standards requirements but only lasted ~25ms for these tests.



single-phase inverter operating at rated power and unity power factor, fault current test has 95% voltage sag on phase A/B



single-phase inverter operating at rated power and unity power factor, high impedance fault current test has 95% voltage sag on phase A/B

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