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Investigations on Two-lead and Three-lead Rotor Connections of Doubly Fed Induction Generator

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Abstract: The doubly-fed induction generator (DFIG) has conventionally been put to use with multi-wattage wind turbines to obtain a sophisticated grid-connected network. This configuration is usually put to use for directly feeding power to grid-connected loads. In this paper, a DFIG with DC excited rotor has been implemented to obtain a novel control strategy which is easier to implement and exploit. The novelty aspect of this work concerns proposing and providing comparison and investigation of two topologies: two-lead and three-lead DFIG connections. These two strategies yield a near-perfect sinusoidal waveform at the stator with very low total harmonic distortion (THD) at steady state. The results presented in this work validate that the usage of DFIG with rotor excited via DC is a simple and easy method for exploiting wind energy. The two-lead and three-lead DFIG configurations can be extensively put to use in Asian countries to boost renewable energy production, thereby decreasing pollution. Increased tapping of the power from wind will result in a reduction in the potential hazards to the environment due to conventional methods of electrical energy generation.

Key words: Asian, DFIG, environment, grid, pollution, THD, three-lead, two-lead.

Introduction

Environmental deterioration due to pollution is a problem of gigantic proportion in the Asian region. The power sector is focusing towards renewable energy so as to mitigate the environmental issues arising out of the conventional generation techniques. Intermittent sources like wind and solar require power electronic converters (PEC) for signal conditioning as well as to maximize energy capture. As the constant speed wind turbines got outmoded, the need for adjustable speed turbines arose, which led to wide adoption of Doubly Fed Induction Generators (DFIG) (Abad et al., 2011; Pena et al., 1996). As compared to permanent magnet (PM) generators, DFIGs are more popular for wind power generation due to low cost of the system, as power rating of the PECs employed is between 25% and 30% (Cárdenas et al., 2013). All this is done while permitting the slip to vary within the range of –33% to +33%. Also, the power characteristic matches the optimal power characteristic of wind turbine which enables users to extract maximum energy. Low weight of geared DFIG drives makes them more preferable over PM direct drive generators even though they have lower torque density (Polinder et al., 2013).

Some DFIG system topologies for alternative applications (Feehally et al., 2015) exploit the natural DFIG flexibility and controllability for minimizing sizing ratings. One of the most important application involves DFIG amalgamation into a dc power system and is significant in wind energy conversion (Holtsmark et al., 2013), distributed generation and dc microgrids (Karlsson et al., 2003; Dragičević et al., 2016) for isolated power systems (Jahromi et al., 2016; Zahedi

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et al., 2013). Thus it can be concluded that the inherent property of DFIG of functioning with changeable speed while yielding stable stator frequency with partial rated power electronic converters can also be put to use for dc voltage generation (Shukla et al., 2017; Chung, 2013).

Various papers related to DFIG dc power control systems (Iacchetti et al., 2015; Misra et al., 2018; Yan et al., 2014) have highlighted different topologies for using DFIGs in DC based applications. This research work aims to re-examine present DFIG based dc power generation topologies. The major novelties in the paper includes an in-depth analysis and comparison of two-lead and three-lead topologies and comparison of total harmonic distortion of the stator sinusoidal output.

System Description

A. Two-Lead DFIG Connection (B level)

The block diagram of two-lead DFIG connection has been illustrated in Figure 1. In this configuration of a DFIG, DC supply is connected across any two rotor terminals. The remaining rotor terminal is connected to the ground via a large resistance. In the simulations carried out for this work, the remaining rotor terminal has been grounded via a resistance equal to 1000 Ω. Simulations have been carried out on two different machines. The rotor of one of the machines has been excited by a dc voltage of 42 V while the other has been excited by a rotor dc voltage of 64 V.

B. Three-Lead DFIG Connection

The block diagram of three-lead DFIG connection has been illustrated in Figure 2. In this configuration of a DFIG, any two rotor terminals are short circuited. DC supply is connected between the shorted rotor terminals

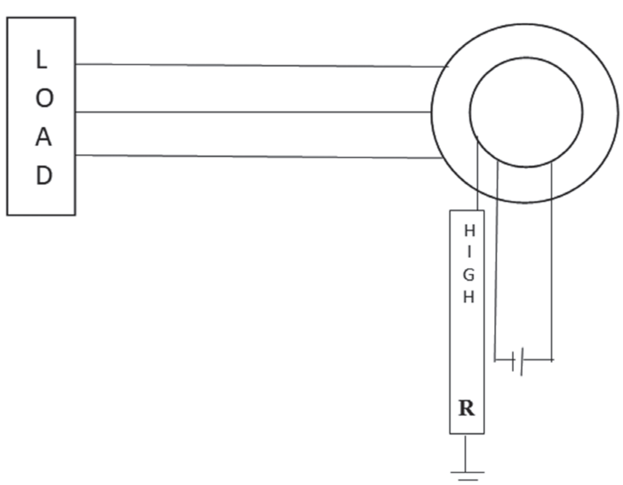

Figure 1: Block diagram for two-lead DFIG connection.

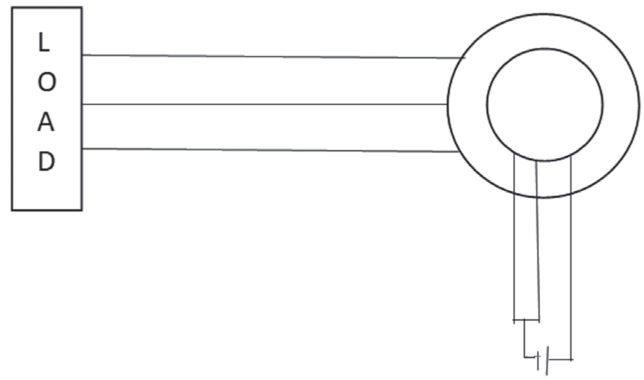

Figure 2: Block diagram for three-lead connection.

and the remaining terminal. Simulations have been carried out on two different machines. The rotor of one of the machines has been excited by a dc voltage of 39 V while the other has been excited by a rotor dc voltage of 55 V.

Analysis of Results Obtained

Table 1 presents the parameters of two different machines, on which the simulation was carried out. Both the machines were configured as a two-lead DFIG as well as a three-lead DFIG. Various aspects of the output waveform have been captured and further analysed.

Table 1: Machine 1 and Machine 2 parameters

Machine parameters	*M/c-1*	*M/c-2*
Nominal (apparent) Power (VA)	750	750
Line voltage (V)	380	380
Frequency (Hz)	50	50
Stator resistance (Ω)	9.5	1.14
Stator inductance (H)	0.02813	0.00703
Rotor resistance (Ω)	8.04	2.818
Rotor inductance (H)	0.02813	0.00703
Mutual inductance (H)	0.165	0.08562
Pole pairs	2	3
Rotor type	Wound	Wound

Figure 3 shows starting transients of the two DFIGs with different DC excitation on rotor.

By comparing all four parts of Figure 3 it is evident that two-lead connection gives faster settling transients in both the machines.

Figure 4 shows the steady state voltage level of the two DFIGs with two-lead connection and three-lead connection.

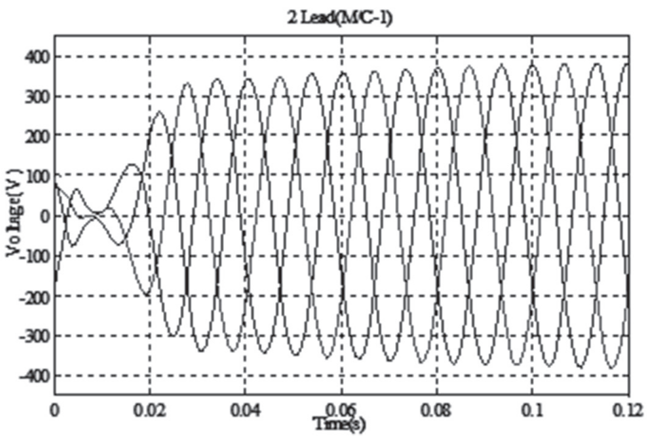

Figure 3a: Starting transients of Two-Lead Machine-1.

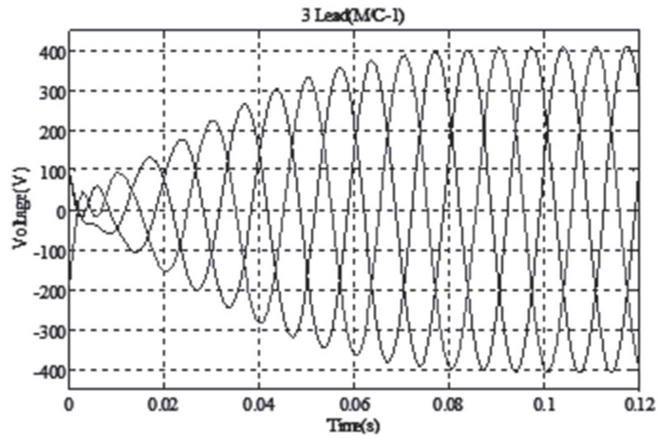

Figure 3b: Starting transients of Three-Lead Machine-1.

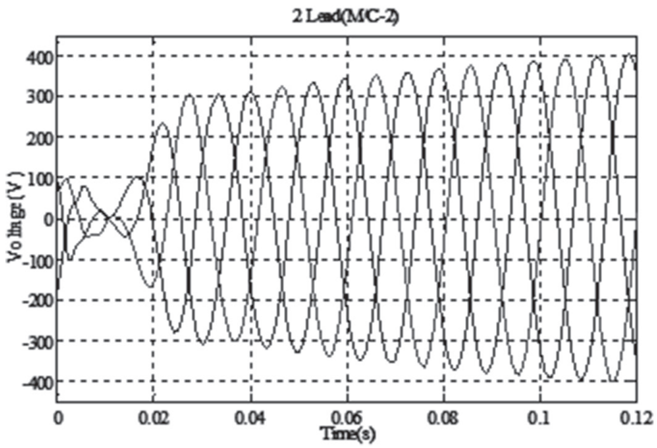

Figure 3c: Starting transients of Two-Lead Machine-2.

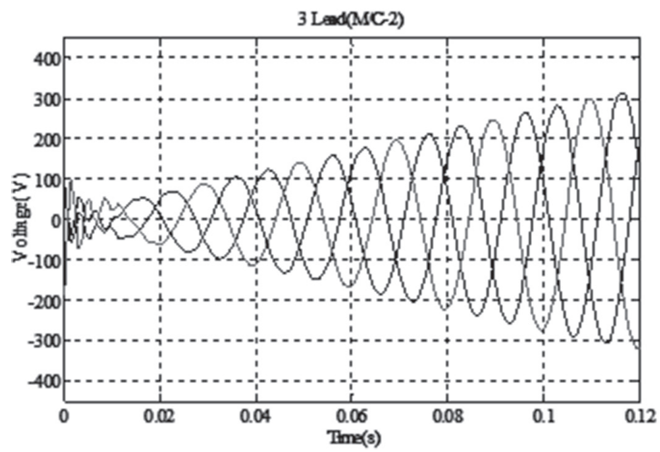

Figure 3d: Starting transients of Three-Lead Machine-2.

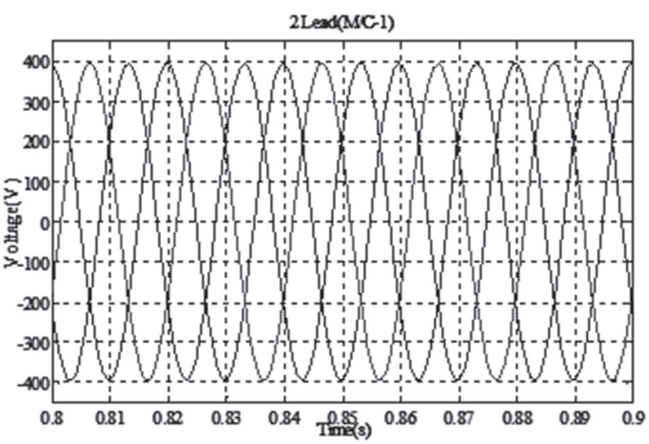

Figure 4a: Steady-state voltage of Two-Lead Machine-1.

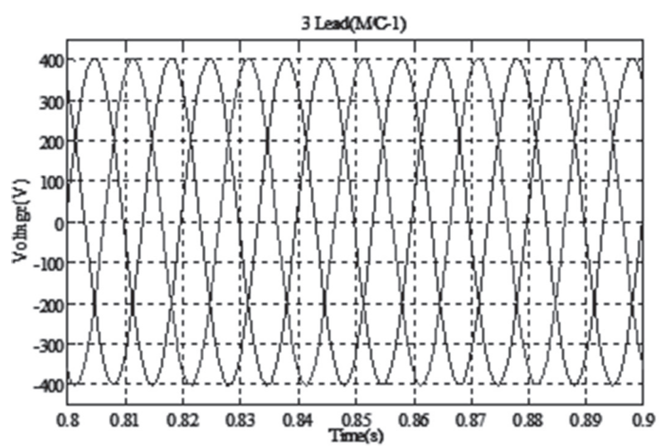

Figure 4b: Steady-state voltage of Three-Lead Machine-1.

By perusing all the four parts of Figure 4, it is inferred that the steady state voltage levels obtained for the two machines are in the range of 390 V to 450 V. The DC applied to the machine rotor is in the range of 40 V to 60 V.

Figure 5 illustrates the THD analysis of the starting transients of the DFIG stator voltage. The THD has been computed from 0 second for 10 cycles, before steady state is attained.

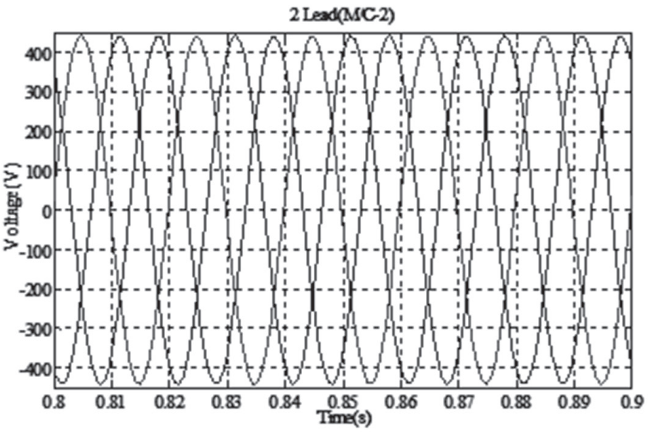

Figure 4c: Steady-state voltage of Two-Lead Machine-2.

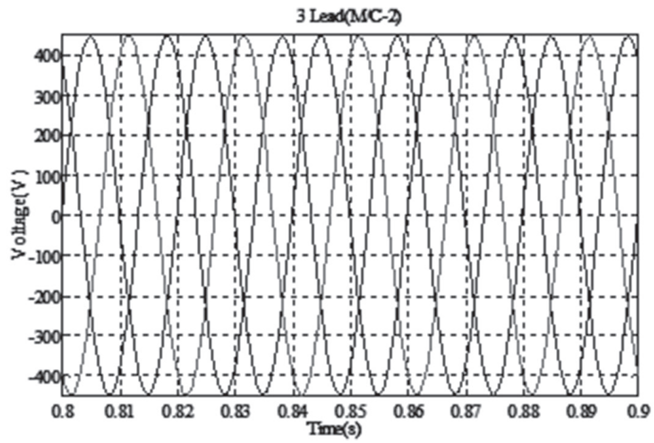

Figure 4d: Steady-state voltage of Three-Lead Machine-2.

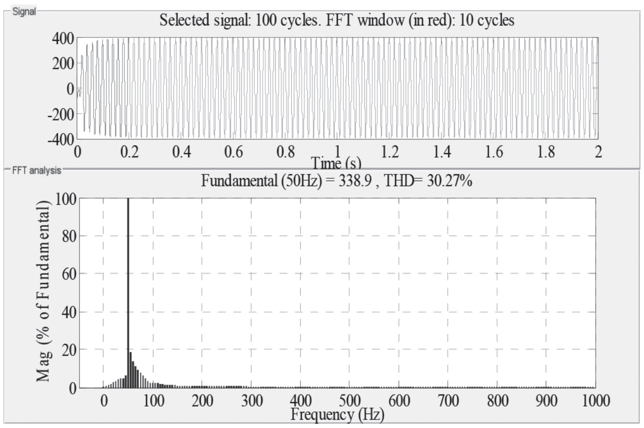

Figure 5a: THD transient analysis of Two-Lead Machine-1.

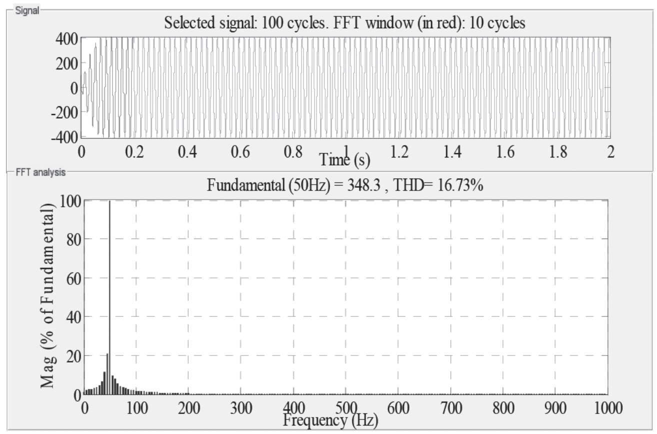

Figure 5b: THD transient analysis of Three-Lead Machine-1.

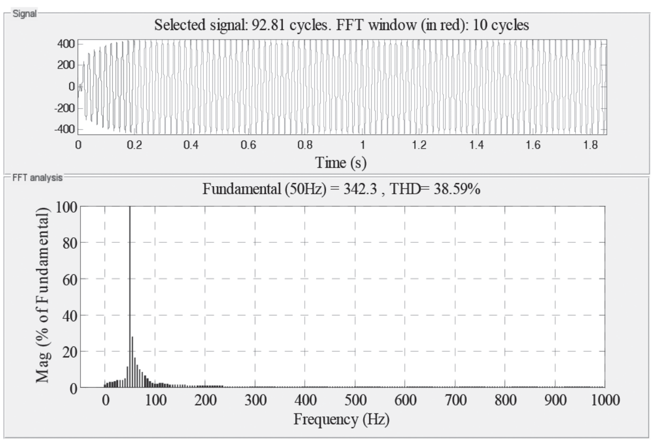

Figure 5c: THD transient analysis of Two-Lead Machine-2.

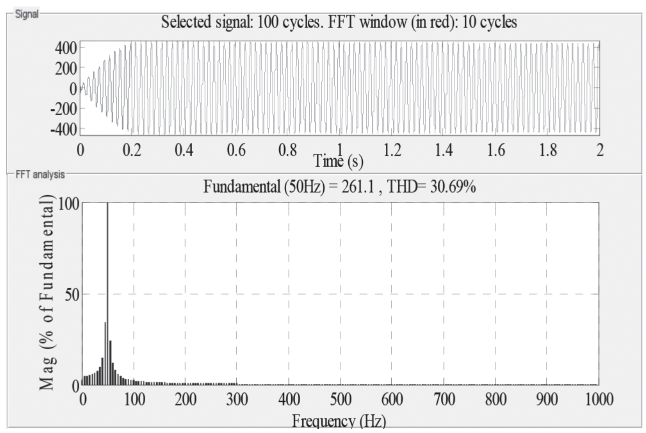

Figure 5d: THD transient analysis of Three-Lead Machine-2.

From Figure 5 it can be observed that for both machines, the three-lead connection yields a much lower value of stator voltage THD as compared to the two-lead connection.

Figure 6 illustrates the THD analysis at steady state of one phase out of the three phases of each DFIG, for both two-lead and three-lead configurations.

The analysis of Figure 6 draws out the conclusion that a near-perfect sinusoidal is obtained in all the cases. Here the fundamental frequency is taken as 50 Hz and all the study about THD has been done with respect to 50 Hz frequency.

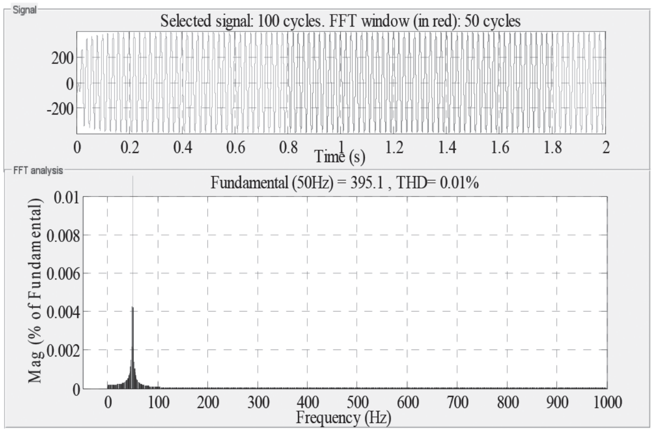

Figure 6a: THD steady-state analysis of Two-Lead Machine-1.

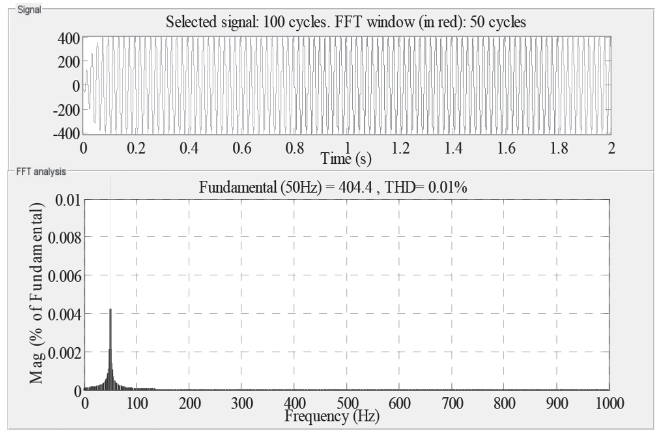

Figure 6b: THD steady-state analysis of Three-Lead Machine-1.

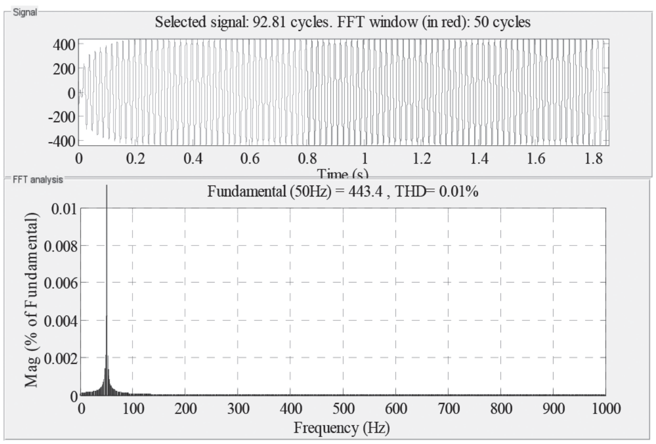

Figure 6c: THD steady-state analysis of Two-Lead Machine-2.

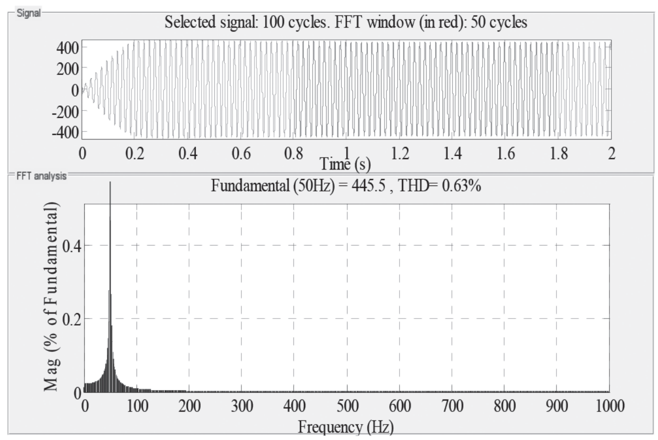

Figure 6d: THD steady-state analysis of Three-Lead Machine-2.

Conclusion

On the basis of comparison of two-lead and three-lead connections, following conclusions can be drawn:

1. DFIG rotor excited through DC is a system with reduced cost and very less complexity because it requires fewer power electronic converters. Hence, it can be readily employed for tapping energy from wind, thereby reducing the burden on conventional sources. A boost in the renewable sector will reduce pollution and lead to a cleaner environment.
2. As compared with the orthodox topologies of DFIG, the reduced cost and complexity of two-lead and three-lead DFIG topologies, make them an attractive option for Asian countries with wind potential.
3. Two-lead DFIG connection gives faster settling transients as compared to its three-lead counterpart.
4. Three-lead DFIG connection yields a much lower value of stator voltage THD as compared to the two-lead connection.

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