INDUSTRIAL SOLUTIONS LABORATORY

Company Information

Company Name	*Kinectrics AES*	Date Submitted	*02/28/2022*
Project Title	*EMI Mitigation to Allow Use of a PWM Variable Frequency Drive as a Induced Voltage Test Power Source for Partial Discharge Testing of Transformers* **(KINECTRICS_PWM)**	Planned Starting Semester	*Fall 2022*

Senior Design Project Description

Personnel

Typical teams will have 4-6 students, with engineering disciplines assigned based on the anticipated Scope of the Project.

Please provide your estimate of staffing in the below table. The Senior Design Committee will adjust as appropriate based on scope and discipline skills.

Discipline	Number	Discipline	Number
Mechanical		Electrical	5
Computer		Systems	

Company and Project Overview:

Kinectrics, Inc. https://www.kinectrics.com

Kinectrics' origins can be traced to 1912 as the technical and research division of Ontario Hydro, a major Canadian electrical utility founded on hydroelectric power, which eventually grew at one point into the largest electrical utility in North America—covering generation from nuclear, fossil, hydroelectric, and renewable sources, as well as transmission and distribution.

From its one-workshop beginnings as Ontario Hydro Research Division (OHRD), Kinectrics has focused on the development and application of advanced technologies for the power industry. Kinectrics is now an independent, privately owned, international testing, inspection, and certification company specializing in the nuclear and power Transmissions and Distribution (T&D) areas.

The Transmission and Distribution Technologies (TDT) business unit focuses on power delivery systems, including the transmission grid, distribution systems and associated equipment. The group's High Voltage, High Current, Arc Hazard Testing, Safety Testing, and Mechanical Testing Labs are among the most pre-eminent testing and certification facilities serving the industry today.

In our Substations Group, we perform field testing and consulting engineering support for a variety of T&D assets "inside the fence" including MV and HV switchgear, station grounding systems, circuit breakers, and transformers. This project will examine ways to improve the EMI shielding performance for partial discharge test equipment.

Partial Discharge Testing

There are three basic dielectric tests performed on all distribution and power transformers in the factory by way of verifying the dielectric integrity of the insulation structures inside the unit. These are the applied voltage test (aka "hipot"), impulse test, and the Induced Voltage Test (IVT). By far, the most onerous of the dielectric tests in terms of stressing the transformer insulation structures is the induced voltage test.

Up to now, the usual source of such high-frequency power has been a Motor-Generator (M-G) set with an induction generator capable of outputting the necessary power at the desired frequency. More recently, electronic Static Frequency Converters (SFC) are employed to produce AC waveforms at frequencies useful for the IVT. Variable Speed Drives (VSD) for electric motor control is one type of industrial SFC that can be employed to produce power at the necessary frequency.

During IVT on a transformer, Partial Discharge (PD) signals are measured as a performance indicator of the insulation system. PD measurement is a fundamental tool used to assess the condition of oil-filled or dry-type power transformers. This unique test method can directly assess the solid insulation of power transformers, tap changers, and bushings.

PD manifests itself in a number of measurable ways: it generates radio frequency energy across a broad spectrum (into the GHz range); it generates small amounts of thermal energy; it generates lightweight hydrocarbon gasses (primarily hydrogen) from the insulating oil (in oil-filled transformers); and it produces audible noise. The measurement of PD using radio detection is a cornerstone of this diagnostic test method.

In performing a PD measurement, it is important that the energization source be PD-free itself, lest it impress PD signals into the transformer being tested either masking any real PD signal being produced in the insulation structure, or causing a false indication that PD exists when it does not.

To be able to use a Variable Frequency Drive (VFD) as a power source for IVT / PD testing has significant benefits, including reduction in weight and physical size, both of which are key attributes for field deployment of IVT equipment. The downside of these devices is that they generate considerable harmonic energy in the frequency bands of interest for PD measurement.

From prior experimental work at Kinectrics, we know that extensive electromagnetic interference (EMI) mitigation measures need to be put in place between the VFD source and the transformer to be tested in order to avoid impressing electrical noise on it that appears as in the same RF bandwidth as partial discharge signals. These EMI mitigation measures must be incorporated along with the booster transformer.

Project Requirements:

Variable Frequency Industrial drives are electronic devices that that use an IGBT circuit topology to synthesize a variable frequency, variable pseudo-sinusoidal voltage output using Pulse-Width Modulation (PWM) of a carrier frequency. The output AC waveform approximates a sine wave.

Because of the fast switching time of the PWM circuitry, the output of a VFD is extremely rich in harmonic energy, extending into the MHz. frequency range. Due to the overlap of the frequencies of the generated RF signal in the VFD output and the radio frequency band of interest during PD measurement, this RF energy is seen by a PD measurement circuit as a massive amount of PD.

To be useful as a IVT power source for PD measurement of a transformer, all the RF energy above ~70 KHz must be removed from the output of the VFD.

In general terms, the project is centered on Electromagnetic Interference (EMI) mitigation strategies to reduce the harmonic content of a VFD power source such that it is useful as a power source for IVT in the field.

Expected Deliverables/Results:

- Identify the electrical noise profile of a typical VFD that might be used as a power source for IVT.
- Identify the impact of operational parameters (carrier frequency, output voltage, output frequency, load current, etc.) on the RF harmonic output of a VFD and what parameters might be changed or configured to minimize harmonic/RF noise in the output of a VFD.
- Develop and implement EMI mitigation measures (e.g. RF filtering; grounding practices; RF barriers, cable shielding, etc.) to reduce VFD harmonic energy to point consistent with < 20 pC in PD signal at the output measured in the 100 kHz to 1 MHz. frequency range.
- Build a prototype circuit that can be an "add-on" device or module to provide the necessary filtering / EMI reduction to reduce harmonic content in the VFD output to levels acceptable for use in PD testing, and demonstrate that it can be economically scaled to high-power, high-current applications (400 volts; 400 kW).
- Show quantifiable results by measuring PD signatures at the "untreated" output of the VFD and the output of the EMI mitigation circuitry.

Disposition of Deliverables at the End of the Project:

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Students are graded based on their display and presentation of their team's work product. It is mandatory that they exhibit at the Expo, so if the work product was tested at the supporter's location, it must be returned to campus for the Expo. After the expo, the team and supporter should arrange the handover of the work product to the industry supporter. This handover must be concluded within 7 days of the Expo.

List here any specific skills, requirements, specific courses, knowledge needed or suggested (If none please state none):

- Electric filter theory and design
- Harmonic analysis / wave synthesis
- Knowledge of spectrum analyzers
- Signal analysis
- Radio frequency circuit analysis, esp. grounding techniques.
- Electromagnetic wave propagation; shielding design
- Specialized circuit components – ferrite cores; coaxial capacitors; feedthrough capacitors and waveguide stubs
- Access to a Faraday cage, radio quiet location, or antenna anechoic chamber might be helpful to minimize the effect of external RF noise sources that could register as PD.