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Grid-Ready, Flexible Transformers to Enhance Resiliency and Operational Flexibility of Transmission Networks

— Technical Presentation —
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1. Abstract

Power transformers are one of the most difficult electric transmission network components to replace in emergency situations. If a spare is not available, a new power transformer must be designed and manufactured, a process that can span many months, even if raw materials and components are readily available. The use of mobile substations and transformers as well as the application of available spares can provide an adequate temporary response when transformers fail due to high overloads, excessive ambient temperatures or other damaging weather events. Flexible characteristics of such emergency components, such as reconnectable voltage, significantly enhance network resilience at generally affordable costs.

In the case of less frequent but more severe events that could cause the failure of massive numbers of transformers, the interconnected grid could collapse for an extended period of time. Repair of failed units is frequently an option; however, as with new transformers, repairs are dependent on availability of long lead-time components and field service personnel.

Prolec GE and GE Research developed a solution specifically for large utilities or groups of utilities where different voltages and impedances may be required when considering the purchase of spares. Instead of being solely dependent on a large pool of highly customized spare units, flexible transformers with multiple low voltage ratings and adjustable impedance capabilities could be a simpler and more cost effective solution, not only for emergencies, but as permanent replacements. This subject has been the topic of U.S. DOE reports and is currently being evaluated by different utility programs, including Grid Assurance, EPRI's STEP and others.

In response to two RFPs from the DOE, the concept of a Flexible Transformer was proposed and tested first by the development of 345kV and 230kV high voltage designs and then by a 100 MVA, 165/69kV prototype autotransformer that was installed on the transmission network of Cooperative Energy Utilities. This process started in September 2016 and was recently completed by successfully field testing the 100 MVA prototype transformer in its operating environment.

In this tutorial, we will present the concept of the Grid-Ready, Flexible Transformer (GRFT), and the electrical system landscape that makes a flexible replacement strategy necessary. We will outline the experience gained by funding, developing, building and testing the prototype unit described above and the challenges associated with integrating such a transformer with common protection systems. Finally, we will discuss opportunities to enhance the flexible operation of future networks with the expectation that those networks will have a higher content of renewable generation resources and energy storage systems not available full-time.

2. Learning Objectives

This presentation is intended to introduce the new concept of GRFT from a technical perspective, to highlight its inherent simplicity and reliability. New operating features come along with the concept of being able to adjust the impedance of a transformer on-line and at full load, allowing the GRFT to compete in the low range with phase shifters. An off-line adjustable impedance will also be demonstrated as an attractive feature.

As a second general interest subject, authors will share experience on overcoming typical challenges for an innovation project involving strong interaction among manufacturers (research, technology development, engineering, manufacturing and test entities), research centers (conceptual validation, specialized testing and interface with funding entities) and users (supply, substation controls, protections, installation and maintenance, interface with TSO).

3. Learning Outcomes

By attending this tutorial, attendees will gain an understanding of the following:

- Typical composition in power ratings, voltages and impedance levels of a population of transmission transformers
- Potential for reduction of the number of replacement units by application of flexible transformers
- Impact of having an off-line adjustable impedance, which would allow for better matching of local replacement conditions and could even be exploited by evolving needs of the network
- Impact of having an on-line adjustable impedance, which would allow for the reduction of short circuit currents at convenience or for regulation of active power flow in a meshed network

4. Presenters’ Biographies

Enrique Betancourt-Ramirez is currently Technical Manager for Prolec GE’s transformer plants, with responsibility to develop technology transfer strategies and control of advanced technology projects. Enrique was an assistant professor for High Voltage Engineering and Simulation of Electromagnetic Transients at the Graduate School of Nuevo Leon State University (UANL) from 1992 to 2012 and is currently a member of the IEEE PES Transformers Committee and of CIGRE SC A2. He is co-developer of several patents, has published several scientific and technical articles and organized multiple Transformer Technology Seminars on behalf of Prolec GE. Enrique graduated from Nuevo Leon State University (UANL) in 1983 with a Bachelor of Science Degree in Electromechanical Engineering. In 1988, he received his master’s degree in Electric Power Engineering from the Technical University of Aachen (RWTH-Aachen).

Juan Castellanos-Gonzalez has worked in a number of different areas within Prolec GE since 1994, including design, manufacturing, test, R&D, forensic engineering and standards. He is author of several technical articles published by IEEE, CIGRE and other institutions. He is a member of the IEEE Transformers Committee and the IEC Technical Committee 14 (Transformers), and the convenor of the Mexican Transformers Committee. He is a technical expert listed in IEC TC14 for thermal design of electrical transformers, overload capacity and thermal evaluation tests. Juan obtained his BSEE and MSEE degrees at the ITESM- Monterrey (Monterrey Tech) in 1991 and 1994 respectively.

Dr. Ibrahima Ndiaye received his Ph.D. from University of Quebec in Chicoutimi in 2007. He has over 15 years of experience in power systems and high voltage engineering and leads technical teams on both government and internal programs. His research includes power transformer design, power system transients, medium voltage DC technologies and integration of renewable energy resources. He has authored and co-authored over 20 scientific papers and technical reports for utility customers. Dr. Ndiaye is also a professional engineer registered in the Ordre des Ingenieurs du Quebec.