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Reverse Power Flow Impact on Transformers

— Technical Presentation —
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1. Abstract

The increase of renewable energy and distributed energy resources (DERs) is upsetting the past normal flow of power from distant large generation sites to large urban centers. Renewable energy is now being connected to the power grid at multiple system points, causing power to flow in a different direction than how the power grid was originally designed. This change in power flow is termed "reverse power flow," and it can have a large, negative impact on installed transformers. According to IEEE C57.12.00, transformers are designed for step down operation (i.e. power flow in one direction) unless otherwise defined, such as for generator step-up (GSU) transformers or system intertie transformers (power in both directions).

Evolving changes to the power grid system will first be presented from a utility perspective. Reverse power flow will require the evaluation of existing transformer assets and new transmission infrastructure. Large additional transformer upgrades/de-rating/replacement costs need to be considered as well as new transmission investment due to reverse power flow.

The impact on different types of transformers from a design perspective will be presented next. Most transformers may not have been designed for reverse power flow. The change in direction of power can cause large changes to the leakage flux pattern, core loss, core temperature, metal part temperature and winding temperature of a transformer. Increased loss and thermal cycling can reduce transformer life. Small increases in excitation voltage can lead to significant magnetizing current increases and harmonics. Comparing the results of various operating conditions, reverse active and reactive power flow are the worst. Restrictions on power flow without the loss of transformer life or transformer replacement may be required.

Reverse power flow can also have an impact on on-load tap changers (OLTCs). The frequency of tap changing operation may be higher, and the tapping range may no longer match system requirements.

Several examples will be presented where multiple studies were conducted on various step-down transformers. These transformers all had dual low voltage (LV) terminals and the flow of power was originally HV to both LVs. The change in power flow from LV to HV and even LV to LV was shown to have a significant negative impact on the transformer's operation and required a large de-rating under reverse power flow scenarios. This impact was different depending on the transformer winding arrangement, core type and clamping design. These case studies are examples of real significant impacts to power transformers under reverse power flow conditions that would not have been known without a study.

2. Learning Objectives

This tutorial provides the following learning opportunities:

- Context for reverse power flow due to changes to power grids caused by increasing renewable generation connection and its variability by nature
- Impact of reverse power flow to utilities with large installed transformer base
- Performance impact for power transformers with reverse power flow
- Effect of reverse power flow on OLTCs
- Cases studies of step-down transformers that required significant de-rating

3. Learning Outcomes

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

- What is reverse power flow and why is it happening
- Why reverse power flow can impact certain power transformers
- Necessity of studying impact to power transformers from a design perspective that will see reverse power flow

4. Presenters' Biographies

Dipl.-Ing. (TU) Rainer Frotscher works for Maschinenfabrik Reinhausen (MR) in Regensburg, Germany, as its senior expert for insulating liquids, where he develops the knowledge within the Reinhausen Group concerning the interaction of solid, liquid and gaseous insulating materials. Rainer's area of expertise is the applicability of insulating liquids and DGA for tap changers, expertise developed through his work on manifold projects and studies to promote the technology of on-load tap changers within the company's R&D department and through his work as an expert for special tap changer applications. He is a member of CIGRE and DKE and contributes to several working groups within CIGRE, IEC, IEEE and DKE. He authored multiple conference papers and journal publications and shares in several patents. Rainer received his master's degree in electrical engineering from the Technical University of Munich/Germany in 1986.

Martin Rave is a principal engineer at ComEd with 30 years of experience. Martin has been a member of ComEd's Distribution Standards Department as an equipment specialist for the past 17 years with previous positions that include equipment specialist in the Substation Equipment Standards Department and an instrumentation and control specialist at Braidwood Nuclear Generating Station. He is a voting member of the Transformers Committee and Vice Chair of "C57.12.38 Single-Phase Compartmental Transformers" and "C57.12.37 Electronic Reporting of Distribution Transformer Test Data" working groups. He has a published technical paper and one patent. Martin received his B.S. Degree in Electrical Engineering from the University of Illinois at Urbana-Champaign.

Ed teNyenhuis is currently working for Hitachi ABB Power Grids in Stoney Creek, Canada, as the operations and technical manager for the company's Transformer Service Group. Ed has worked in past positions as a transformer design engineer, research engineer, engineering manager and quality manager at ABB locations in Sweden, U.S. and Canada. He is Vice Chair of the Transformers Committee, Canadian Chairman of IEC TC 14 and a member of CIGRE A2.59 "Site Repair of Transformers" and A2.62 "Transformer Failures" working groups. Ed has published more than 20 technical papers and has one patent. He received his B.A.Sc. Degree in Electrical Engineering from University of Waterloo in Canada and his Master of Engineering Degree from North Carolina State University. He is a Professional Engineer (PE) in the province of Ontario.

Dr. Parag Upadhyay is a senior member of IEEE and presently working as a principal R&D scientist at North American Power Grid Research, Hitachi ABB Power Grids (HAPG) in Raleigh, North Carolina, where he is involved in supporting the industry's university and corporate research collaborations. Parag specializes in strategic technology planning, technology assessments and R&D, project management and leadership in the areas of transformers, rotating electrical machines, drives and electromagnetic devices. He has over 25 years of experience and a professional record of developing novel technologies, identifying/mitigating engineering challenges to bring about higher technology readiness levels. Parag has been principal investigator and project manager for the U.S. Department of Energy funded project on "Novel Concept for Flexible and Resilient Large Power Transformers" and is leading renewable interface transformer activity at HAPG. He is a life member of ISTE, has reviewed several conference and journal publications, was general co-chair for the IEEE Southeastcon 2020 held in Raleigh, contributed as program committee member to IEEE Intermag conferences and chaired several conference sessions.