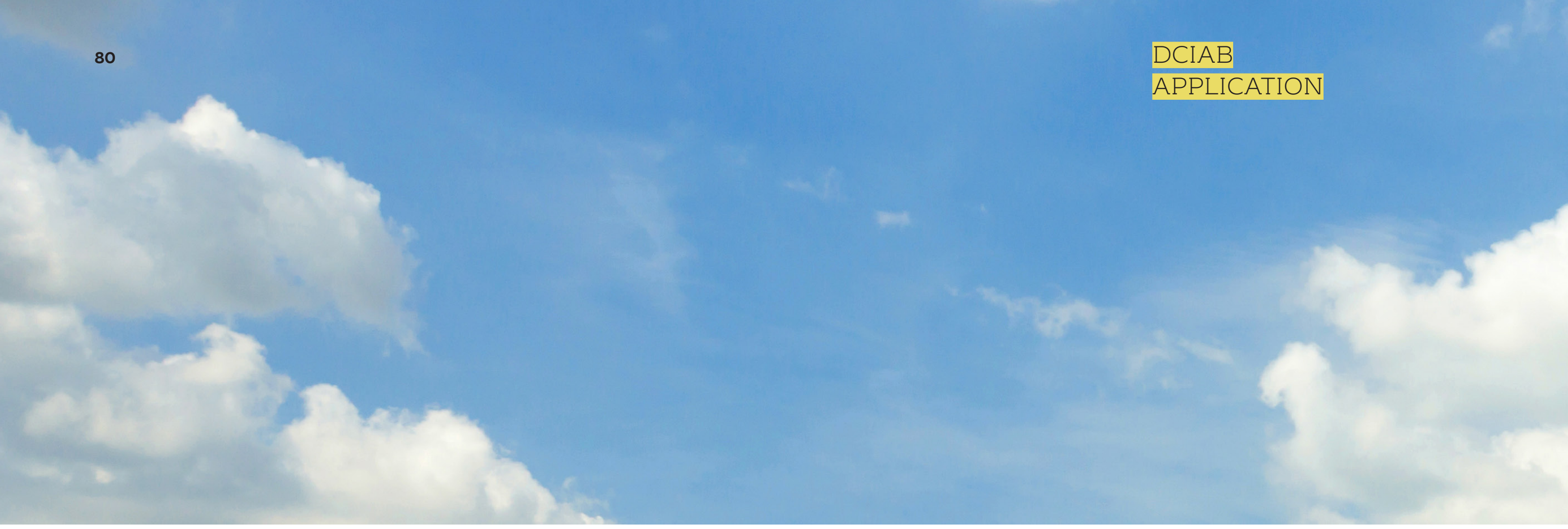

Distribution-Center-in-a-Box as an application of Voltage Regulating Distribution Transformers

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Photo: Maschinenfabrik Reinhausen

Tu-Anh Tran works as Business Development Manager for Maschinenfabrik Reinhausen, a subsidiary of the Reinhausen Group. She engages with utilities, industry partners and relevant stakeholders to adopt voltage regulation technology for the distribution grids. As a solution that solves several distribution grid challenges due to emerging trends, Tu Anh works with utilities and industry partners to adopt this smart-grid technology as part of grid modernization and grid reinforcement efforts.

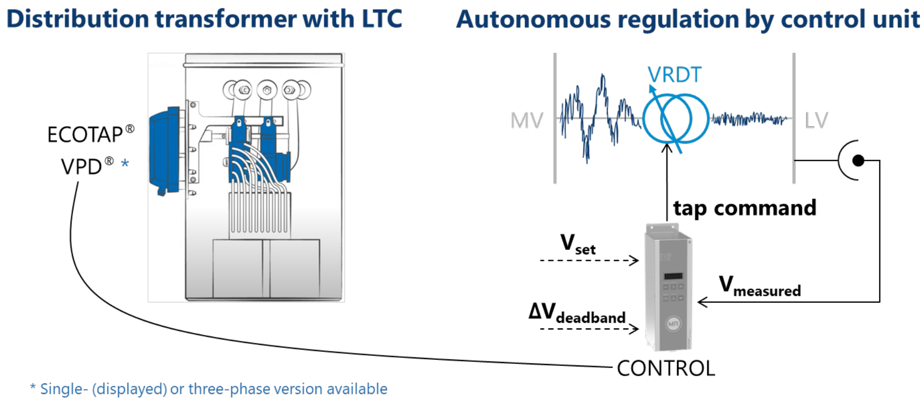

Figure 1.
Voltage Regulating Distribution Transformer

1. Introduction

Population growth and electrification trends are major drivers for increasing loads on the US electric distribution systems. Utilities continue to develop new strategies and devise innovative ways to design, engineer and construct substations and transformer equipment. Combined with the increasing needs to lower capital expenditure due to regulatory and ratepayer pressure, utilities often look for ways to innovate. As part of this initiative, the distribution center in a box (DCIAB) project was developed as a new application for voltage regulating distribution transformers.

1.1 Voltage Regulating Distribution Transformers (VRDT)

Traditionally, voltage regulation can be done by using an off circuit tap changer, which allows for transformer windings to be added or substracted in distinct steps only when the tap changer is de-energized.

Voltage regulating distribution transformers (VRDT) belong to a new class of distribution transformers that are equipped with an on-load tap-changer to enable a stable voltage output under load.

Standard grid planning follows ANSI C84, requiring distribution system voltages to be within ±5% of nominal voltage with respect to 10-minute average voltage [1]. Voltage regulation from primary feeders is distributed throughout the entire distribution lines, creating a voltage limit constraint within the voltage bandwidth. At the primary substation feeders, voltage usually remains stable and independent of the feed in load. However, the delivered voltage experiences a larger spread further down the distribution line. In conventional distribution transformers, voltage on the primary side is linked to voltage on the secondary side. The effect of this mechanism means high voltage on the primary side equates to high voltage on the secondary side. With the implementation of a voltage regulating distribution transformer, a decoupling effect takes place between the medium and low voltage grid [2]. From the distribution voltage profile, voltage starting from the substation to the line voltage regulator may be above nominal voltage so that there is room for voltage drop over the distribution transformer to the connection points of the last meter in the line. This is true for both peak load and low load scenario.

First Gen DCIAB	Next Gen DCIAB
• 9.375 MVA • 34.4 kV HV - 200 kV BIL • 13.2 kV LV – 110 kV BIL rating • 34.5 kV lightning arresters, 200 kV BIL • 65°C rise ONAN • De-energized tap changer with ± 2 x 2.616% tap • Three 333-A single phase regulators • Dimensions: 121.3 (L) 140.6 (W) 117.9 (H) inches • Oil volume = 1320 gallons	• 9.375 MVA • 34.4 kV Delta HV - 200 kV BIL Primary • 13.2 Y/7.6 kV LV - 110 kV BIL rating • Nominal Impedance: 6.5% • 65°C rise ONAN • ECOTAP® VPD® 3-phase 40.5 kV 100-A LTC ∘ ~12 operations/day • Dimensions: 121.3 (L) 140.6 (W) 117.9 (H) inches • Oil volume = 1314 gallons • Total weight = 43,500 pounds

Table 1. First Gen vs. Next Gen DCIAB Comparison

The VRDT decouples MV from LV grid such that any voltage that comes from the primary side, it does not affect the voltage on the secondary side. Connected customer meters continue to receive stable secondary voltage despite the condition of the voltagefrom the primary side.

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1.2 OLTC Specifications

A standard distribution transformer integrated with an on-load tap-changer becomes a voltage regulating distribution transformer (VRDT). Manufactured by Maschinenfabrik Reinhausen, the ECOTAP® VPD® is a compact load tap changer that enables service transformers to respond to changes in voltage under load. Having the ability to respond to changes in voltage under load and the decoupling of medium voltage from low voltage grids, the VRDT opens up various potential applications for utilities, industries and distributed generation.

Based on a high speed, resistor-type vacuum technology, this OLTC can operate either in 9 or 17 positions at 1.25 or 2.5 percent per step in common configurations. Designed for single phase and three phase, the equipment is rated at 30 A or 100 A, with the highest equipment voltage at 40.5 kV. The ECOTAP® VPD® OLTC exemplifies high reliability by enabling 500, 000 operations exceeding the typical lifetime of the transformer. The ECOTAP® VPD® comes with motor drive, the load tap changer and a control unit.

2. DCIAB as an application of VRDTs

2.1 ComEd Overview

Commonwealth Edison Company, also known as ComEd, is the largest electric utility in the state of Illinois, serving 4 million customers throughout northern Illinois and 70% of the state's population. ComEd provides electric services within an 11,400-square-mile territory and manages over 90,000 miles of power lines [3]. In 2012, as part of the Illinois Energy Infrastructure Modernization Act, ComEd stepped up significant electric grid improvements throughout its service area through a 10-year grid modernization plan [4].

Photo: Maschinenfabrik Reinhausen

Figure 2.
A traditional substation that requires easement, fencing and wildlife protection

Figure 3.
First Gen DCIAB [5]

Figure 4.
Next Gen DCIAB

The utility recognizes the needs for a strong and modern electric grid as the basis for its modernization plan. As a result, grid infrastructure upgrades are part of the core initiatives at ComEd.

2.2 First Gen Distribution Center-in-a-Box

The fisrt generation DCIAB project started in 2005 as part of the initiative within ComEd's Innovation Team. Driven by efforts to be more cost effective, the team came together with equipment manufacturers to design the existing equipment, a substation design project called Substation-in-a-Box. This equipment is a line voltage regulator in the form of a 34.4 kV substation with 3 single-phase voltage regulators and a switch.

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The transformer is equipped with a 600-A recloser that is connected inside the LV air compartment. The recloser controls are mounted on the outside of the cable compartment for accessibility.

This design made a big leap, transforming a typical distribution center substation into a more compact solution and therefore enabled ComEd to add distribution services directly at the location where the growing loads requirements exist.

The 2005 DCIAB project serves to increase reliability and reduce substation design and construction costs. Unlike the traditional distribution center substation layout, which requires security fencing for overhead incoming and outgoing wires, to and from the exposed transformer bushings, the pad-mounted DCIAB style allows both the 34.5 kV and the 13.2 kV lines to run underground. This new concept, with its reduced footprint, would be unfenced, with less overhead lines that leads to better visual aesthetic to the community.

Figure 5.
Cable connections are dead-front inside the pad-mounted transformer

2.3 Next Gen Distribution-Center-in-a-Box (DCIAB)

Located 100 miles southwest of Chicago, the rural town of Tonica is a village in LaSalle County, Illinois. Economic growth in Tonica fueled the need for additional substation capacity. In 2019, a ComEd team went to the drawing board and came up with a re-design of the existing First Gen DCIAB.

The next generation DCIAB features a novel design with several new characteristics. The 3 individual single phase voltage regulators are now replaced with an on-load tap-changer (LTC), the ECOTAP® VPD® from Machinenfabrik Reinhausen, further reducing the footprint of the substation significantly. It is installed on the high side voltage with a regulating range of ±10%. The 40.5 kV, 100-A three-phase LTC provides the same capability as the previous 3 individual single-phase voltage regulators, enabling voltage regulation under load to ensure Tonica residents receive voltage within the prescribed limit.

As part of the project's priorities based on safety and reliability, the DCIAB retained its dead front design to enhance safety for operating personnel, a cornerstone feature in the previous version of the equipment. In addition, a de-energized tap changer is also added for safety and convenience while maintaining equipment.

2.4 Cost Benefit Analysis of Next Gen DCIAB

Compared to the first gen DCIAB, the next gen DCIAB features a significantly smaller footprint than its predecessor. This allows for a single 34kV to 13.2 kV transformer to be installed "right-of-way" without building a substation or the needs for additional fencing and wildlife protection. The total cost estimate for the current DCIAB transformer equipment is approximately half of its original model, as illustrated in the table below.

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ComEd commissioned the DCIAB project in October of 2020 and subsequently energized the project in March 2021.

3. Conclusion

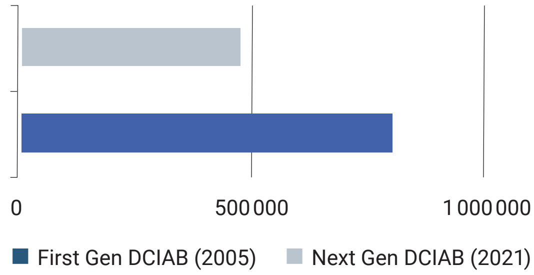
A new class of distribution transformers, the voltage regulating distribution transformer, is fast becoming an important and economical solution for grid operators to solve challenges for the distribution grids. These challenges stem from the increased loads due to electrification movement, distributed energy resources, and regulatory pressure to reduce capital expenditures as a benefit to ratepayers. The DCIAB project from Commonwealth Edison is a clear example of its viability in the grid operators' toolkit. For ComEd, it is now the new standard for DCIAB designs. For other US utilities, new applications continue to be assessed where the VRDT may serve as a beneficial solution for the distribution grids.

	First Gen DCIAB (2005)	Next Gen DCIAB (2021)
Transformer	92,50%	100,00%
Land Easement	6,25%	0,00%
Fencing	1,25%	0,00%
Total Project Cost (in %)	100,00%	100,00%

Table 2.
DCIAB Cost Comparison

Project estimates do not include additional easement for fencing, equipment foundations, civil work, mid-grade or high-grade fencing.

DCIAB Cost Comparison



A new class of distribution transformers, the voltage regulating distribution transformer, is fast becoming an important and economical solution for grid operators to solve challenges for the distribution grids.

Photo: Maschinenfabrik Reinhausen

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