Assessment of increasing number of operations of On-Load Tap Changers (OLTC) in HV/HV distributions transformers

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***Abstract*— The significant increase in the number of operations of On-Load Tap Changers (OLTC) in HV/HV distribution transformers within the Spanish electrical grid has raised concerns regarding the maintenance and durability of the equipment. This study aims to analyze the correlation between OLTC operations and voltage variations, particularly in the context of increasing renewable energy penetration. By collecting and analyzing historical data from various substations, patterns and trends that could explain the surge in tap changes were identified. The results suggest that voltage instability may be related to both the network operator's actions and the distribution company's operations, highlighting the need for advanced management strategies to mitigate negative effects on grid stability and efficiency.. (*Abstract*)**

Keywords*— On-Load Tap Changer (OLTC), HV/HV Distribution Transformers, Voltage Variations, Renewable Energy Penetration, Grid Stability, Correlation Analysis.

I. Introduction

A. Background and motivation

In recent years, there has been a significant increase in the maneuverability of on-load tap changers (OLTC) in power transformers within the Spanish distribution network. This phenomenon has been particularly noticeable in 2023, where the number of tap changes has risen considerably, raising concerns about the impact on maintenance and the durability of the equipment.

The increase in the frequency of maneuvers, which in some cases has exceeded 10,000 operations per year and in others has reached even more than 20,000, poses serious challenges. This situation not only affects the maintenance cycles and the wear of the equipment but also could compromise the stability and operational efficiency of the electrical grid.

The need for this research is based on the concern that the increase in the maneuverability of power transformers could lead to accelerated equipment deterioration and an increase in maintenance costs and frequency. Therefore, it is crucial to determine the underlying causes of this phenomenon and evaluate possible solutions in the future to mitigate its negative effects.

To address this issue, this analysis has been initiated with a focus on tap changes, with special attention to the correlations between these changes and the voltages. The study first examines whether there are indeed more tap changes in the case at hand and then explores the potential causes.

Considering the evolution of the grid towards increasingly distributed generation and the reduction of large generating units, which previously provided greater stability and voltage control, this problem takes on great importance.

B. Research objectives

TThe primary objective of this project is to analyze the correlation between OLTC operations and voltage variations, particularly in the context of increasing renewable energy penetration. By examining historical data from selected substations, the project seeks to identify patterns and trends that may explain the surge in tap changes. Specifically, the study will establish correlations between the parameters of the transformers in order to determine if the voltage instability is due to the network operator or the distribution company.

II. Literature Review

A. What is an OTLC?

An On-Load Tap Changer (OLTC) is a crucial component in power transformers, enabling voltage regulation without interrupting the electrical supply. This function is essential in modern power systems, particularly with the integration of variable renewable energy sources like solar and wind.

B. Mechanism and operation

OLTCs adjust the transformer's turns ratio by moving the tap changer across different winding points, allowing the output voltage to be increased or decreased as needed. Traditional mechanical OLTCs, while reliable, require significant maintenance due to arcing and wear.

C. Advances in OTLC technology

Recent advancements include electronic and solid-state OLTCs, which offer improved reliability and efficiency by eliminating issues like arcing. These new technologies, combined with microcontroller-based controls and digital twin approaches, enhance voltage stability and prolong operational cycles.

D. Intelligent Control Systems for OLTCs

Intelligent control systems, utilizing real-time data and machine learning, optimize OLTC operations to respond dynamically to grid conditions. These systems help manage voltage profiles and accommodate distributed generation, offering a cost-effective alternative to traditional grid reinforcement methods.

E. Condition monitoring and fault diagnosis

Regular monitoring of OLTCs is critical for maintaining power system stability. Advances in AI and machine learning have improved predictive maintenance and fault diagnosis, allowing for early detection of issues and reducing the risk of failures

F. The Role of OTLC transformers

OLTCs are increasingly important in maintaining voltage stability in grids with high renewable energy penetration. They help balance loads, mitigate voltage dips, and ensure the reliability of power systems, particularly in regions with limited grid interconnections.

G. Impact of renewable energy integration

The integration of renewable energy sources introduces challenges in voltage regulation due to their variability. OLTCs, particularly those with advanced electronic controls, play a key role in managing these fluctuations, ensuring grid stability in the face of increasing renewable energy deployment.

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III. METHODOLGY

A. Data collection

Data was sourced from Endesa's SCADA system, focusing on input/output voltages, active/reactive power, and tap changer positions. Substations were selected based on significant increases in tap changer activity and the availability of reliable data, particularly those connected to high levels of solar energy.

B. Selected substations

Seven substations across different regions of Spain were chosen. These included substations like Alcores and Costaluz, which are heavily influenced by solar generation, and others like Besos, connected to a mix of solar and cogeneration. Each substation's transformers were analyzed for patterns in tap changes.

C. Data treatment

Given the non-continuous nature of the SCADA data, the analysis used Kernel Density Estimation (KDE) to visualize data distributions and segment data into time windows (e.g., 15 minutes, 1 hour, 1 day). Key statistics like mean, standard deviation, and Pearson correlation coefficients were calculated for each segment to understand the relationships between the variables.

D. Data visualization

The data was visualized using Kernel Density Estimation (KDE) to create smooth probability density functions. This approach allowed for the identification of patterns and outliers in the data. Density-adjusted histograms were also used to compare distributions of the variables across different substations and time periods.

IV. DATA ANALYSIS

A. Model description

The analysis aimed to establish correlations between key parameters: input voltage (Vin), output voltage (Vout), active power (P), reactive power (Q), and the tap changer position (T). The goal was to determine whether voltage instability originates from upstream (grid-related) or downstream (distribution network) sources. The relationship between these variables was assessed to identify patterns causing the increase in tap changes.

B. Parameter Interactions

Input Voltage (Vin): This reflects the voltage supplied by the grid. The correlation between Vin and T helps determine if upstream fluctuations are driving tap changes.

Output Voltage (Vout): Maintained by the transformer, Vout is adjusted by the tap changer. A high correlation between Vout and T would suggest that the tap changes are primarily a response to downstream conditions.

Active and Reactive Power (P and Q): These variables influence voltage drops in the network. The analysis explored how variations in P and Q correlate with changes in T, providing insight into the load effects on the transformer.

C. Correlation Analysis

Pearson correlation coefficients were calculated to quantify the relationships between these variables. The analysis was performed across different time windows (e.g., 15 minutes, 1 hour, 1 day) to capture both short-term and long-term trends. This helped in identifying whether the instability was consistent over time or linked to specific conditions.

D. Key findings

The analysis revealed distinct patterns of correlation between the tap changer position and the other variables. In some substations, a strong correlation with Vin indicated upstream influences, while in others, correlations with P and Q suggested that load changes in the distribution network were driving the increased tap activity. These findings are crucial for understanding the root causes of the increased tap changes and for developing strategies to mitigate their impact.

V. CONCLUSIONS

The analysis showed that both upstream factors (such as grid-supplied voltage fluctuations) and downstream factors (such as changes in load conditions) contribute to the instability observed. The findings highlight the critical role of OLTCs in maintaining voltage stability but also underscore the stress placed on these components due to the evolving energy landscape.

The frequent tap changes are largely driven by the integration of variable renewable energy sources, which cause frequent and sometimes severe voltage fluctuations.

In some substations, upstream grid voltage instability was the primary driver of tap changes, while in others, the load demand and reactive power fluctuations were more influential.

The current OLTC operations are not fully optimized to handle the new challenges posed by increased renewable energy sources, leading to excessive wear and maintenance needs.

VI. POTENTIAL IMPROVEMENTS

The methodology applied in this study could be further refined and expanded upon in several ways. One potential improvement is to replicate the study using data from years when the number of tap changer operations was within normal levels. This would help to determine if the observed influences and correlations remain consistent or if they vary under different operational conditions. Such a comparison could provide deeper insights into the factors that trigger tap changer operations under varying network loads and conditions.

Another area for improvement is conducting field investigations to ensure the accuracy and reliability of the measurement devices used in the study. This would involve

verifying that the meters are accurately capturing the intended variables, identifying their measurement thresholds, and performing error analysis to reduce uncertainty in the data.

Such an approach would enhance the reliability of the findings and provide a clearer understanding of the factors influencing tap changer operations.

Lastly, it would be essential to rule out unnecessary tap changer operations due to potential issues within the distribution network. This could be achieved by obtaining a comprehensive topology of the substations and their connected downstream networks, including detailed information on the use of capacitor banks and the algorithms governing their operation. Understanding the full network configuration and the logic behind voltage regulation devices would enable more precise identification of the causes behind tap changer actions, thereby improving the overall stability and efficiency of the network.

VII. BIBLIOGRAPHY

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