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Research Original Article

The Application of Greedy Algorithm in OLTC Tap Setting for Voltage Stability of a 60 MVA Power Transformer

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Abstract
Abstract. The On Load Tap Changer (OLTC) is an electrical device that functions as a tap changer under load, allowing the adjustment of transformer windings without requiring a power shutdown. To maintain a constant output voltage of 20 kV on the secondary side of a transformer, OLTCs are employed in 60 MVA power transformers. Voltage instability in a power generation system leads to increased OLTC operations. This study aims to analyze the optimization of OLTC tap position settings to enhance voltage stability in a 60 MVA power transformer using the Greedy Algorithm, based on primary voltage, secondary voltage, and OLTC tap position. The research was conducted over the course of one week, from June 1 to June 7, 2024. The results show that, when using the Greedy Algorithm, Transformer 1 required only 8 tap position changes, compared to 11 changes with manual calculations and actual data. Similarly, Transformer 2 experienced 7 tap changes, while manual calculations and actual data recorded 10 changes. These findings indicate that, by using the Greedy Algorithm, the transformer taps operate less frequently, which is beneficial for the longevity of the transformer taps. This study concludes that the Greedy Algorithm is effective as an optimization method for OLTC tap settings to maintain voltage stability in 60 MVA transformers.
Keywords: OLTC, Greedy algorithm, transformer, substation

Introduction
Currently, Indonesia is undergoing development across various sectors, with electricity recognized as a fundamental human need. As economic growth accelerates, the demand for electrical energy rises correspondingly. The increasing reliance on electricity is evidenced by population growth, investment, and technological advancements, which support both domestic and industrial activities. Given the strategic importance of electrical energy, its availability and sustainability must adhere to the principles of reliability, safety, and environmental friendliness.

As the primary electricity provider, PLN is expected to deliver excellent service to consumers, necessitating a power system characterized by high quality, continuity, and reliability. Achieving stable and constant voltage at predetermined levels is crucial, yet fluctuations in load and transmission losses complicate this task. The On Load Tap Changer (OLTC) is an electrical device that adjusts tap settings under load, allowing for the addition or reduction of transformer windings without outages. To maintain a constant output voltage of 20 kV on the secondary side of a 60 MVA power transformer, an OLTC is employed, which operates automatically in response to voltage drops due to load changes and transmission losses.

Voltage instability in a generation system increases the frequency of OLTC operations. In existing systems, OLTC movement is controlled by an Automatic Voltage Regulator (AVR) with step-by-step tap changes, which is inefficient due to excessive operation, leading to overheating and a greater risk of mechanical failure. Optimizing OLTC tap position settings is expected to minimize tap movement, reducing the risk of damage and achieving secondary voltage stability. The optimization, using the Greedy Algorithm, aims to determine the most efficient tap position directly, where primary voltage (Vp) and secondary voltage (Vs) serve as inputs, and tap changes represent the target. This approach is anticipated to enhance OLTC efficiency in stabilizing voltage.

The quality of electrical energy is affected by voltage instability, influencing the stability of the power system during generation, transmission, and distribution. One contributing factor to voltage instability is suboptimal OLTC operation. This final project will discuss optimizing OLTC tap position settings to enhance secondary voltage stability in a 60 MVA power transformer using the Greedy Algorithm.

Literature Review
Power Transformer
A power transformer is an electrical device used to convert electrical voltage from one level to another. This

transformer is commonly employed in electrical distribution systems to change voltage levels from high to low or vice versa. This capability allows electricity to be transmitted through distribution networks with greater efficiency and reduces energy losses. The role of power transformers is critical in electrical distribution systems, as they facilitate the transportation of electricity more efficiently while minimizing energy losses. Power transformers are also utilized in industrial applications to adjust the voltage used by production equipment.

A power transformer consists of two main components: the primary winding and the secondary winding. The primary winding receives input voltage from the power source, while the secondary winding delivers the desired output voltage. This transformer alters the voltage by changing the turns ratio between the primary and secondary windings.

On Load Tap Changer (OLTC)

Almost all power transformers in substations are equipped with tap changers. Their function is to adjust the transformation ratio of the transformer to maintain a stable voltage on the secondary side. The On-Load Tap Changer (OLTC) is a type of tap changer that operates by shifting the tap position of the transformer while it is under load. OLTC can be operated both manually and automatically.

To ensure the continuity of power flow during the tap position shifting process, the load current must not be interrupted, and no part of the transformer winding should experience a short circuit. Therefore, before transitioning from one tap position to another, the target tap must be connected beforehand. Due to the voltage difference between the taps, impedance in the form of resistance or reactance is required to limit the circulating current, which can be described as the short-circuit current between the two taps.

Greedy Algorithm

The greedy algorithm is a widely used programming technique that effectively addresses various optimization and decision-making problems. The fundamental principle of the greedy algorithm involves making locally optimal choices at each stage or step, with the expectation of achieving a globally optimal solution overall.

In its implementation, the greedy algorithm often requires a strategy or rule to determine the optimal choice at each step. This strategy may vary depending on the specific problem being addressed.

Materials & Methods

Research Procedure

The research procedure is illustrated in a flow chart designed to facilitate the research process. For simulation generation, as depicted in the following figure.

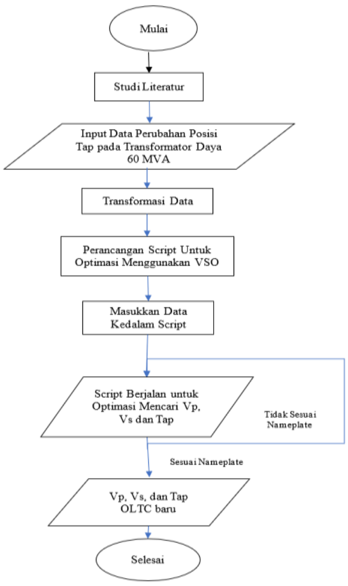

Figure 1. Research Flow Diagram

Data Collection Method

The data used in this research includes primary voltage (Vp) values obtained from actual data, as well as actual OLTC tap data, while the secondary voltage (Vs) and target tap positions represent the desired outcomes. The data collection methods used in this study consist of several stages: (1) interviews and discussions, which involve gathering data by conducting question-and-answer sessions with experts related to the subject matter, (2) observation, which involves direct review of the equipment or processes under investigation, (3) literature review and library research, conducted by reading relevant books and journals from available sources, and (4) analysis, which includes performing calculations for the automatic transformer tap settings using the Greedy Algorithm.

One Line Diagram of Denai Substasion

Below is a one-line diagram of the denai substation:

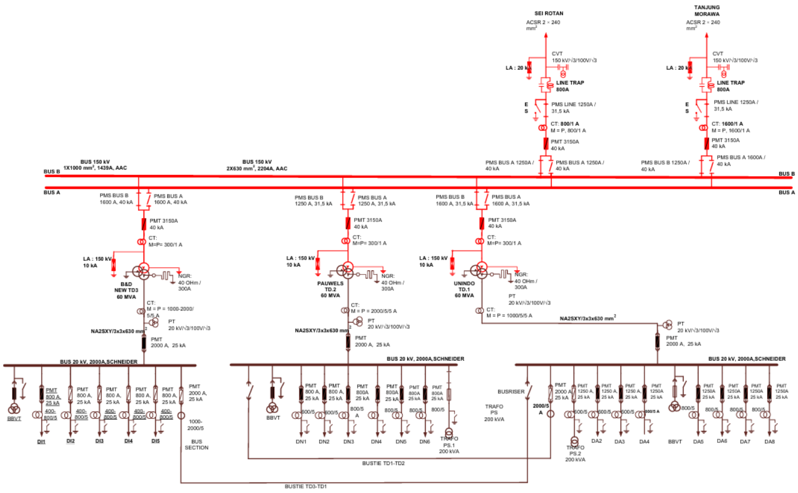

Figure 2. One Line Diagram of Denai Substasion

OLTC Transformer Tap Calculation

The operation of a transformer is based on the difference between the primary voltage (Vp) and the secondary voltage (Vs), which arises from the difference in the number of primary windings (Np) and secondary windings (Ns). This relationship can be expressed as follows:

$$\frac{Vp}{Vs} = \frac{Np}{Ns} \quad (1)$$

Since the winding ratio is not always stable, an OLTC (On Load Tap Changer) is used to adjust the number of windings on either the primary or secondary side, resulting in changes to the secondary voltage. Each tap change causes a voltage shift, which is measured based on the tap range from the nominal voltage. To determine this tap range, it is necessary to calculate the ratio between the highest and lowest taps, then compare it with the nominal tap and convert it into a percentage, as shown in the following formula:

$$\text{Rentang tap} = \frac{\Delta Vtotal}{Vnominal} \times 100\% \quad (2)$$

So each tap will give a voltage change of:

$$\Delta Vtap = \frac{Rentang\ tap}{Jumlah\ tap - 1} \quad (3)$$

In OLTC transformer tap settings, manual calculations can be used to adjust the OLTC tap based on the difference between the actual voltage (obtained during the research) and the nominal voltage. The formula to determine the tap change, derived from the previous equation, is as follows:

$$\Delta Tap = \frac{\left(\frac{Vs,aktual}{Vs,nominal} - 1\right) \times 100}{\Delta Vtap} \quad (4)$$

OLTC Tap Settings in Visual Study Code Software

The following is a display of the Greedy Algorithm using Visual Studio Code software:

```python
import random

def get_primary_voltage_range_for_tap(tap_setting):
    voltage_ranges = {
        1: (165.000, 163.125),
        2: (163.125, 161.250),
        3: (161.250, 159.375),
        4: (159.375, 157.500),
        5: (157.500, 155.625),
        6: (155.625, 153.750),
        7: (153.750, 151.875),
        8: (151.875, 150.000),
        9: (150.000, 148.125),
        10: (148.125, 146.25),
        11: (146.25, 144.375),
        12: (144.375, 142.500),
        13: (142.500, 140.625),
        14: (140.625, 138.750),
        15: (138.750, 136.875),
        16: (136.875, 135.000),
        17: (135.000, 135.000),
    }
    return voltage_ranges

def determine_tap_for_primary_voltage(V_primary):
    voltage_ranges = get_primary_voltage_range_for_tap(None)
    tap_setting = None

    for tap, (min_voltage, max_voltage) in voltage_ranges.items():
        if min_voltage >= V_primary >= max_voltage:
            tap_setting = tap
            break

    if tap_setting is None:
        if V_primary > max(voltage_ranges[1]):
            tap_setting = 1
        elif V_primary < min(voltage_ranges[17]):
            tap_setting = 17

    return tap_setting

def simulate_oltc_optimization(V_primary):
    tap_setting = determine_tap_for_primary_voltage(V_primary)
    V_primary_updated = (get_primary_voltage_range_for_tap(tap_setting)[tap_setting][0] + get_primary_voltage_range_for_tap(tap_setting)[tap_setting][1]) / 2

    V_secondary_output = (V_primary * 21000) / V_primary_updated

    print(f"Initial Primary Voltage: {V_primary:.3f} V")
    print(f"Determined Tap Setting: {tap_setting}")
    print(f"Updated Primary Voltage: {V_primary_updated:.3f} V")
    print(f"Calculated Secondary Voltage: {V_secondary_output:.3f} V")

V_primary_input = 153.400

print("Simulation Start - Adjusting OLTC Tap Setting Based on Given Primary Voltage:")
simulate_oltc_optimization(V_primary_input)
```

Figure 3. Script for OLTC tap setting with greedy algorithm using visual studio code

Results and Discussion

Manual Calculation Results of OLTC Tap Settings

In this study, calculations were performed using Equation 4, which aimed to produce the OLTC tap settings. The results of the calculations using Equation 4 are presented in Table 1.

Table 1. Results of OLTC Tap Setting using equation

	Unindo transformer			Pauwels transformer		
Date	Vs actual	$\Delta Vtap$	Tap	Vs actual	$\Delta Vtap$	Tap
1 June 2024	21	1,25%	9; 10	21	1,5 %	8; 9
2 June 2024	21	1,25%	10; 11	21	1,5 %	8; 9
3 June 2024	20,8	1,25%	10; 11	20,9	1,5 %	8
4June 2024	21	1,25%	11	21	1,5 %	10
5 June 2024	20,8	1,25%	12; 10; 9 ;12	20,8	1,5 %	10; 9; 7; 10
6 June 2024	21	1,25%	11; 9	21	1,5 %	10; 8; 9
7 June 2024	21	1,25%	9	21	1,5 %	8; 10

As shown in the table above, the OLTC tap settings for the Unindo and Pauwels transformers were adjusted using Equation 4, with a nominal secondary voltage of 20 kV. Through manual calculation, it was determined that from June 1 to June 7, 2024, the OLTC transformer at Unindo underwent 11 tap position changes. Similarly, it was calculated that the OLTC transformer at Pauwels underwent 13 tap position changes during the same period.

As for the graphical form of data on changes in OLTC Transformer 1 Unindo tap as follows:

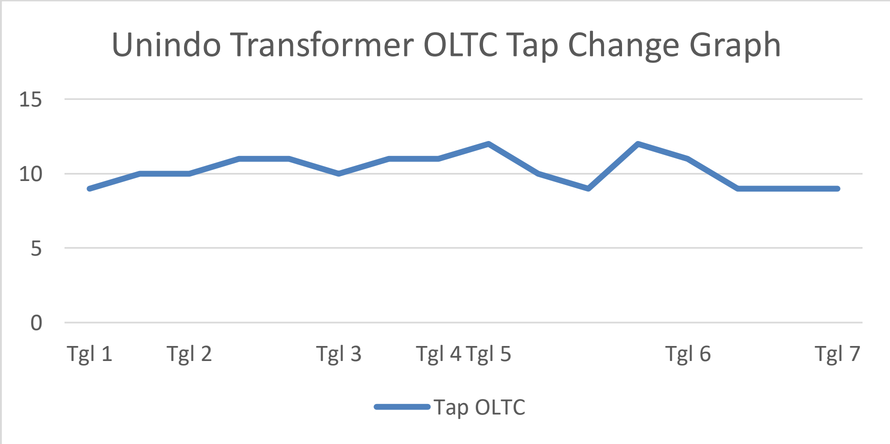

Figure 4. Unindo Transformer 1 OLTC Tap Change Graph Using Equation (4)

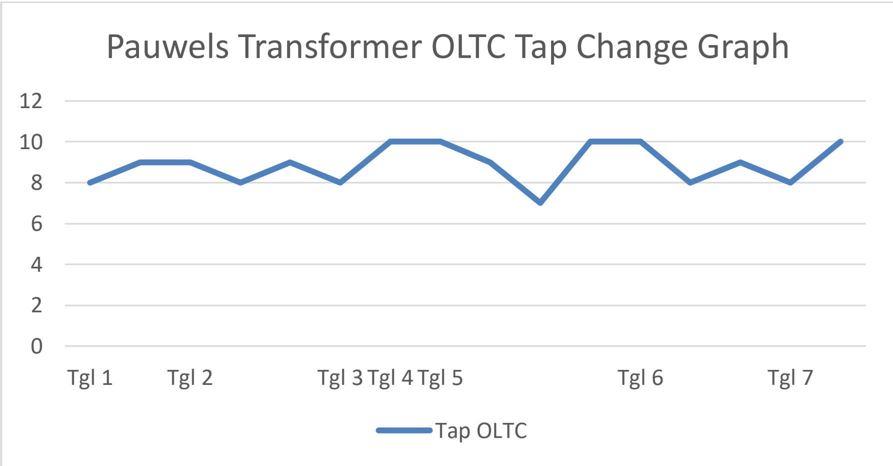

Figure 5. Pauwels Transformer 1 OLTC Tap Change Graph Using Equation (4)

OLTC Tap Setting Results Using Greedy Algorithm

The following are the results of OLTC tap settings using the Greedy Algorithm for June 1 - 7, 2024, as shown in table 2.

Table 2. Results of OLTC Tap Setting Using Greedy Algorithm

	Unindo transformer			Pauwels transformer		
Date	Vp (V)	Vs (V)	Tap	Vp (V)	Vs (V)	Tap
1 June 2024	156.562	20924.5	5; 7	155.625	20915.6	5; 7
2 June 2024	152.812	21025.7	7	153.375	20948.6	6
3 June 2024	154.688	20906.6	6; 8	153.375	21085.5	6; 7
4June 2024	152.812	21025.7	7	153.375	20948.6	6
5 June 2024	152.812	21080.7	7; 8	153.375	20948.6	6; 7
6 June 2024	152.812	20003.2	6; 7	153.375	20948.6	6; 7
7 June 2024	152.812	21025.7	7	153.375	20962.3	6

In the table above shows data on the results of OLTC voltage and tap after using the Greedy Algorithm, which is for 7 days sampled every hour on transformers 1 and 2. In transformer 1, the Unindo branded transformer only makes 8 changes in tap position, which before setting the tap using the Greedy Algorithm (using AVR) the transformer makes as many as 11 changes of tap. While in transformer 2, namely the Pauwels branded transformer when using the Greedy Algorithm, it only makes 7 changes of tap, compared to before using the Greedy Algorithm, it makes 10 changes of tap position. This indicates that by using the Greedy Algorithm the transformer tap works less, this is useful for the durability of the transformer tap. If the transformer tap works too often, it will cause the transformer to heat up quickly and be easily damaged. By using the Greedy Algorithm, the tap displacement can be in accordance with the nameplate on the transformer so that it can be more stable. In the table it can also be seen that at certain hours the transformer tap changes every day. This is due to the increase in load at certain hours, which causes the transformer tap to move position to stabilize the voltage. It can also be seen that when the load rises, the secondary voltage will decrease.

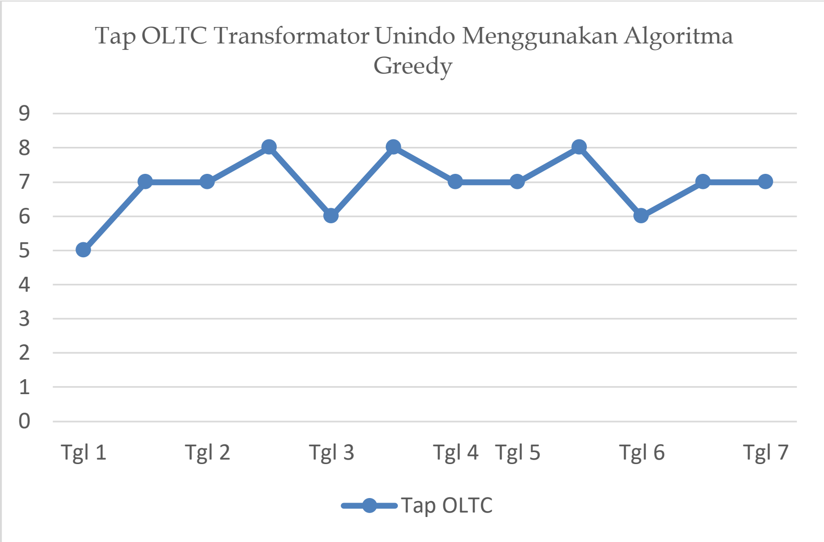

Figure 6. Unindo Transformer OLTC Tap Using Greedy Algorithm

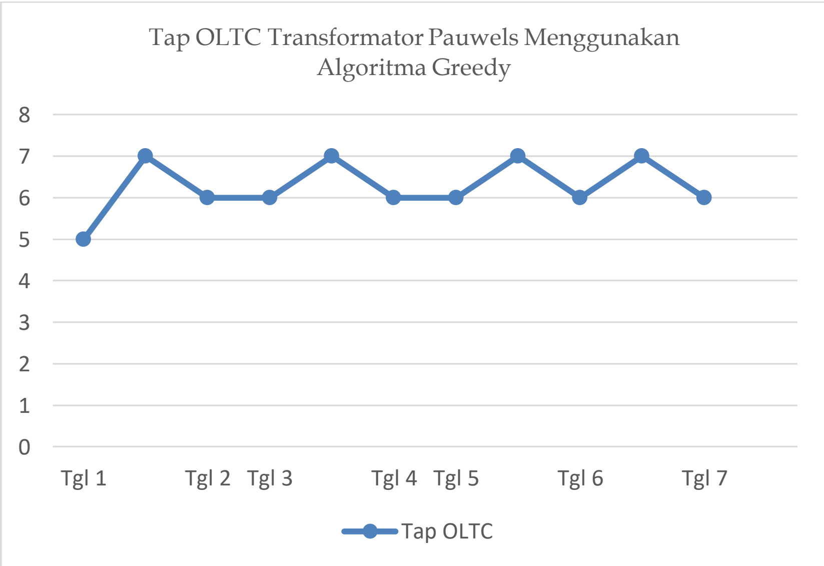

Figure 7. Pauwels Transformer OLTC Tap Using Greedy Algorithm

Comparison of Measurement Value Efficiency Results and Optimization Results

The efficiency of the comparison between the measurement value and the optimization result is required, which is obtained from the comparison between the measurement value and the optimization result and is loaded in percentage form by multiplying the comparison by 100%, which is loaded into table 3:

Table 3. Comparison of Measurement Value Efficiency Results and Optimization Results

	Unindo transformer			Pauwels transformer		
Date	Tegangan Aktual	Tegangan Optimasi (kV)	Efesiensi	Tegangan Aktual	Tegangan Optimasi (kV)	Efesiensi
1 June 2024	155	156,5	99,04	155	155,6	99,61
2 June 2024	154	152,8	100,79	154	153,3	100,46
3 June 2024	154	154,6	99,61	154	153,3	100,46
4June 2024	153	152,8	100,13	153	153,3	99,8
5 June 2024	152	152,8	99,48	153	153,3	99,8
6 June 2024	153	152,8	100,13	153	153,3	99,8

7 June 2024	153	152,8	100,13	153	153,3	99,8

The actual voltage reflects the performance of the transformers based on the current settings of the On-Load Tap Changer (OLTC), which may adhere to nameplate specifications or other standard regulations. When the actual voltage deviates from the desired standards (for instance, being too high or too low), it can adversely affect the overall system performance and voltage stability. The optimized voltage is derived from the greedy optimization algorithm, aimed at adjusting the OLTC taps to bring the voltage closer to optimal values. In this context, "optimal" refers to maintaining voltage within permissible ranges, enhancing energy efficiency, and minimizing power losses in the network.

From the calculations presented in the table, data from June 1 to June 7, 2024, indicate that nearly all measurements approached 100% efficiency. For example, throughout various hours, minor differences between the actual voltage and the optimized voltage were observed. In the case of the Unindo transformer, the actual voltage of 155 kV was optimized to 156.5 kV, resulting in an efficiency of 99.04%. Similarly, the Pauwels transformer exhibited a slight optimization, with the actual voltage varying from 155 kV to 155.6 kV, yielding a slightly higher efficiency of 99.61%. The efficiencies ranged from 99% to over 100%. An efficiency exceeding 100% suggests that the optimized voltage is approaching or even surpassing the ideal voltage required for specific loads, while remaining within safe limits.

The average efficiency nearing 100% indicates that the optimization method employed is highly effective in reducing voltage deviations from optimal values. This reflects that the system operates within an efficient range, with minimal power losses. The small discrepancies between actual and optimized voltages suggest that the network conditions are close to optimal; nevertheless, these improvements enhance system efficiency, particularly in reducing voltage fluctuations that could impact grid stability.

Conclusions

Following the optimization using the Greedy Algorithm, which was previously implemented with Automatic Voltage Regulation (AVR), the tap settings of the On-Load Tap Changer (OLTC) are now aligned with the transformer's nameplate specifications, thereby enabling the transformer to operate more efficiently. After the optimization of the OLTC taps using the Greedy Algorithm, Transformer 1 recorded only 8 tap position changes, a reduction from the 11 changes observed prior to optimization. Similarly, Transformer 2 experienced 7 tap position changes, down from 10. This indicates that the use of the Greedy Algorithm results in less frequent operation of the transformer taps, which is beneficial for their longevity.

The average efficiency nearing 100% demonstrates that the optimization method employed is highly effective in minimizing voltage deviations from optimal values. This outcome reflects that the system operates within an efficient range, resulting in minimal power losses. The small discrepancies between the actual and optimized voltages suggest that the network conditions are close to the optimal state; nevertheless, these improvements enhance overall system efficiency, particularly in reducing voltage fluctuations that could potentially impact grid stability. It can also be concluded that the OLTC tap setting with the calculation using the formula is much different from using the Greedy Algorithm, this shows that the Greedy Algorithm proves to be more efficient in determining the voltage and setting the OLTC tap to be better.

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