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Non-Limiting Operation of The On-Load Tap Changing Transformer, and Its Effect on Voltage Stability, with Regards to The Nineveh Electrical Grid

Abstract. *The achievement of voltage stability is among the most prominent challenges faced by grid operators. In the past, generator excitation regulation was the only method available, for restoring the voltage to its rated values. However, rapid developments in the areas of power grids and power stations, has led to the need of a new technique, for controlling the voltage level, and maintaining the system in the voltage stability band. On-load tap changing (OLTC) is currently among the most widely employed methods, for improving the stability of the power system voltage. OLTC restores the voltage value, whether the disturbance occurs on its primary or secondary side. While a minor disturbance is easily overcome by OLTC, its capacity for restoring the voltage level, during a significant disturbance, is dependent on its ratings and setting values. The failure of the OLTC transformer, to restore the voltage value within a short period, may result in a collapse of the voltage system, when the transformer proceeds with reverse action. A simulation model in MATLAB Simulink shows the effect of OLTC on the Nineveh power grid.*

Streszczenie. *Osiągnięcie stabilności napięcia jest jednym z najważniejszych wyzwań, przed jakimi stają operatorzy sieci. W przeszłości regulacja wzbudzenia generatora była jedyną dostępną metodą przywracania napięcia do wartości znamionowych. Jednak szybki rozwój w obszarach sieci elektroenergetycznych i elektrowni spowodował konieczność opracowania nowej techniki kontroli poziomu napięcia i utrzymywania systemu w paśmie stabilności napięcia. Zmiana zaczepów pod obciążeniem (OLTC) jest obecnie jedną z najczęściej stosowanych metod poprawy stabilności napięcia systemu elektroenergetycznego. PPZ przywraca wartość napięcia, niezależnie od tego, czy zakłócenie występuje po stronie pierwotnej czy wtórnej. Podczas gdy małe zakłócenie jest łatwo przezwyciężane przez PPZ, jego zdolność do przywracania poziomu napięcia podczas znacznego zakłócenia zależy od jego wartości znamionowych i nastawczych. Awaria transformatora PPZ przywracająca w krótkim czasie wartość napięcia może skutkować załamaniem się układu napięciowego, gdy transformator działa odwrotnie.Model symulacyjny w MATLAB Simulink pokazuje wpływ PPZ na sieć energetyczną Niniwy.* (***Nieograniczające działanie transformatora z przełączaniem zaczepów pod obciążeniem i jego wpływ na stabilność napięcia w odniesieniu do sieci elektrycznej Niniwy***)

Keywords: OLTC, Voltage stability, Transformer reverse action, Performance improvement, MATLAB Simulink, Voltage collapse.
Słowa kluczowe: PPZ, Stabilność napięcia, Odwrotne działanie transformatora, Poprawa wydajności, MATLAB Simulink. .

Introduction

Extensive power systems face the possibility of voltage instability, due to the heavy loads involved, and the frequency of disturbances, which have a negative impact on the performance of the grid [1]. Several techniques have been employed to deter the collapse of the power system and ensure uninterrupted power supply to users. These include shunt capacitance [2], the use of FACTS devices [3], the development of distribution generator plants [4], the installation of OLTC approaches [5], and the supplement of energy storage plants [6] or the hybrid stations. OLTC is widely used for power systems in which the power flow is one-directional [7], such as in the Nineveh power grid.

The OLTC turn ratio n is variable. The change in turn ratio occurs, through an alteration in the number of turns, with regards to one of the transformer coils. While one coil is fixed (the main coil), the other is variable (the auxiliary coil). The auxiliary coil is equipped with several taps, with each tap presenting a different number of coil turns [8].

The controller unit decides on the tap number, by comparing the output voltage with the reference voltage, to subsequently contact a specified tap, at the main coil terminal [9].

The auxiliary coil, and the control unit with the taping mechanism, is known as the transformer tap changer (TC). The tap changer unit may be added to either the primary side, or the secondary side, of the power transformer. Generally, in terms of connection, the tap changer added to the high voltage side is more reliable. This can be attributed to the high voltage windings, sited on the outer side of the cylindrical coil. Also, due to the low current of the high voltage side windings, the addition of the tap changer to the secondary side enhances the switching process [10].

The OLTC approach standards and settings, as regards to the load, should be carefully selected. The setting values are crucial, as they directly affect the range of voltage stability, and consequently, the OLTC regulating performance. The OLTC standards and settings also have an effect on the transferred power, transmission lines loss, load current, and the operational costs [11].

As such, manufacturers and researchers associated to OLTC transformers, are constantly seeking out innovative techniques, to render OLTC more reliable and quicker, whether in terms of the tap controller, or the tap type [12], [13], [14], [15].

While the purpose of OLTC is mainly to improve and raise the power systems voltage stability, it is also at times the source of its collapse [16], through the occurrence known as transformer reverse action [17]. However, transformer reverse action is rare, and only happens when there is matching between the system parameters (transmission line impedance Z_T, load impedance Z_L, OLTC turn ratio n) [18].

In this paper, the relationship between the load power S_L, load voltage V_L, transmission line impedance Z_T and OLTC turn ratio *n* was uncovered. The effect of OLTC on the Nineveh power grid is discussed, and the system is simulated in MATLAB. Several approaches are applied on the simulated system, to improve the performance of the transformer.

Voltage stability and collapse point of a power system

All power systems come with acceptable limits. These limits are termed the voltage stability region. The voltage stability limits are the voltage values, which enable the system to function without damage to the load or system devices. The occurrence of an abnormal condition causes the system voltage to rise or fall. The system can be stabilized if the voltage can be returned to its rated values. Typically, a voltage fall is caused by a heavy load or a significant disturbance. If left unchecked, a progressive voltage fall will transfer the system into the instability region, and eventually lead to its collapse [19].

The collapse point is the point, at which the system power and voltage begin to fall irrevocably. It is an indication, that the point of maximum power, that the system can deliver to the load on (P-V) curve, has been reached [20].

The occurrence of a disturbance affects the system voltage. A drop in voltage to below the acceptable limit, activates an under-voltage protection relay, which prevents possible damage, stemming from the low voltage [21].

Determining the value of n for a stable system

Figure 1 depicts a simple power system, showing the relationship between the transformer turn ratio, and equivalent system parameters.

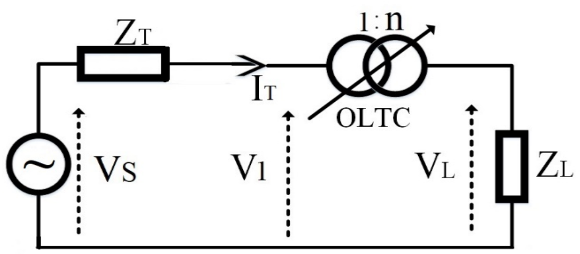

Fig.1. Equivalent circuit for power system with OLTC.

Z_T is the transmission line impedance and internal impedance of the source.
Z_L is the load impedance, n is the transformer turn ratio, V_S is the source voltage, and V_1 is the OLTC primary side voltage.

(1) $$V_S = (Z_T I_T) + V_1$$

(2) $$I_T = \frac{V_S}{Z_T + {Z_L}/{n^2}}$$

(3) $$V_L = nV_1$$

(4) $$V_L = nV_S - \frac{V_S Z_T n^3}{(n^2 Z_T) + Z_L}$$

In the equation, the change in the load voltage V_L is due to the change, in the transformer turn ratio *n*. Thus, to return the system to the stability region, when a voltage drop happens, the rate of load voltage, brought about by the transformer turn ratio, needs to be positive. If it is negative, the system voltage will continue falling, until collapse occurs (reverse action).

If $\frac{\partial V_L}{\partial n} < 0$, then:

(5) $$V_S Z_L{}^2 - n_2 V_S Z_T Z_L < 0$$

(6) $$Z_L = \frac{V_L{}^2}{S_L{}^*}$$

Then the value of n, which will cause reverse action, is expressed as:

(7) $$n > \frac{V_L}{(S_L{}^* Z_T)^{0.5}}$$

If $\frac{\partial V_L}{\partial n} > 0$, then the value of n, for the system to be stabilized, is:

(8) $$n < \frac{V_L}{(S_L{}^* Z_T)^{0.5}}$$

While at

(9) $$n = \frac{V_L}{(S_L{}^* Z_T)^{0.5}}$$

the operation of the system will be faced with a critical risk of collapse situation.

OLTC impact on stability region limits and reverse action [22]**.**

The occurrence of a disturbance prompts the OLTC to alter its turn ratio and restore the value of the system voltage. An extensive disturbance effect can lead to the collapse of the system, and the fall of the P-V curve to zero. At times, the OLTC system may cause collapse, when relationship (8) is verified.

Reverse action is set off, when the transformer increases the turn ratio, in its attempt to restore the voltage value. However, this increase, in the turn ratio, causes the output voltage to drop even further.

When the values of V_L, Z_T, S_L and n are verified by Equation (9), the system is at a critical point on the P-V curve.

Any subsequent increase, in the load on the OLTC, causes a decrease in value, on the right-hand side of Equation (9). This will result in reverse action, as Equation 7 will be verified, and the system will begin to fail.

In such a situation, the OLTC will attempt to improve the system voltage by increasing the turn ratio *n*. Increasing the turn ratio *n*, however, raises the value on the right-hand side of the relationship (7).

The OLTC will then proceed to repeatedly increase *n*, in a desperate attempt to restore the voltage, and return the system to the stability region. This course of action will only quicken the collapse of the system, as it will serve to continually increase the right-hand side of the relationship. This, briefly, defines the OLTC reverse action.

Positive effect of OLTC

To better understand the impact of OLTC on the power system, a model of Nineveh city is simulated in MATLAB Simulink, to demonstrate the positive effects of OLTC. Several techniques are simulated, to emphasize on the need for a proper selection of an OLTC transformer, with regards to the load, system type and the OLTC controller variables setting.

As mentioned earlier, the OLTC controller prompts an increase in the transformer turn ratio, upon an indication of a fall in the output voltage. The fall in output voltage is attributed either to an increase in the load, or a decrease in the input voltage, due to a source voltage drop, or a heavy load on another bus, close to the transformer input [9].

In this paper, the effect of the OLTC2 on bus 7 voltage, and the effect of maximum power transferred through OLTC2 between bus 2 and 7, revealed two different cases. The Nineveh power system is illustrated in Fig. 2.

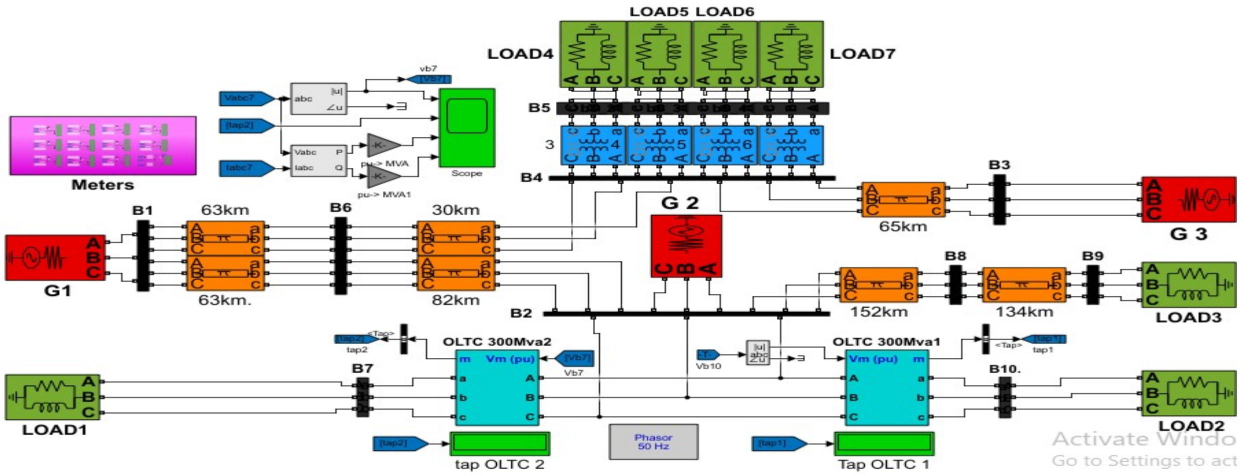

Fig. 2. Nineveh power system grid in MATLAB Simulink.

In the first case, the load gradually increased with constant source voltage. However, in the second case, while the load gradually increased, the source voltage systematically decreased.

- **The first case modeling**: A comparison between a system with, and a system without, OLTC, under a similar variable load, is discussed. The load increased up to the point when the overload protection relay is activated and sends out a trip signal at P = 290 MW. In such a situation, the role of OLTC is to maintain the voltage within the acceptable range. As shown in Table 1, without OLTC the system trips at V_{B7} = 0.964 p.u., while with OLTC the system trips at V_{B7} (V_{out}) = 0.996 p.u. The role of OLTC on the P-V curve is depicted in Fig. 3.
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Table 1: Comparison between a system with and without OLTC, with the system operating with a variable load and fixed source.

	Without (OLTC)	With (OLTC)
P_{max} (MW)	290.0	290.0
V_{B7} (V_{out}) at overload trip point	0.9640	0.9960
V_{B2} (V_{in}) at overload trip point	1.0000	1.0000

- **The Second case modeling**: Here, the comparison is similar, but with a variable source, and a comparable variable load. Under these conditions, the load increases while the source voltage decreases, until the point when the under-voltage protection relay is activated, and transmits a trip signal at V_{B7} (V_{out}) = 0.864 p.u.

While the output power will not reach the value of the overload relay setting, the voltage drop will cause collapse, and the under-voltage protection will be activated. Without OLTC the system collapses at P = 238 MW, V_{B7} (V_{out}) = 0.9355 p.u., V_{B2} (V_{in}) = 0.94 p.u., and trips at V_{B2} (V_{in}) = 0.86 p.u. With OLTC the system collapses at P = 270.5 MW, V_{B7} (V_{out}) = 0.999 p.u., V_{B2} (V_{in}) = 0.96 p.u., and trips at V_{B2} (V_{in}) = 0.78 p.u. (Table 2). Fig. 4 shows the role of OLTC in the system with the P-V curve.

Table 2. Comparison between a system with and without OLTC, when operating with a variable source and a variable load.

	Without (OLTC)	With (OLTC)
P_{max} (MW)	238.0	270.50
V_{B7} (V_{out}) at collapse point	0.9350	0.9990
V_{B2} (V_{in}) at collapse point	0.9600	0.9400
V_{B2} (V_{in}) at under voltage trip point	0.8600	0.7800

Improving the OLTC performance in the Nineveh power system grid

The performance of the OLTC transformer is dependent on its standards and settings. A maximum performance can be derived from OLTC, if the OLTC settings and standards are suitable for the system type, and the type of disturbance can be anticipated. Transformer standards are determined by the step voltage level, and the number of steps involved. The delay time and the switching time are settings that can be altered by the operator.

The values of step voltage, number of steps, delay time, and switching time, directly affect the OLTC performance, and consequently, the maximum power and voltage of the system. An increase in the step voltage and number of steps, as well as a decrease in the value of the delay time and switching time, can serve to raise the performance level of OLTC [16].

Put simply, the OLTC performance can be enhanced by alterations, which increases its ability to conform to the voltage changes.

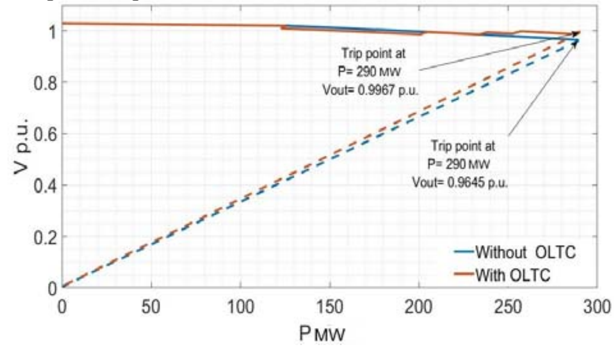

Fig. 3. OLTC effect on power system with variable load and constant source.

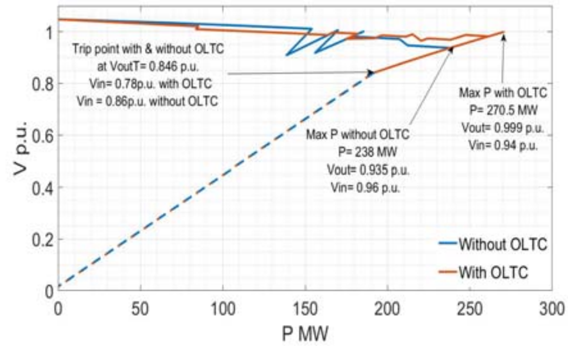

Fig. 4. OLTC effect with variable load and variable source.

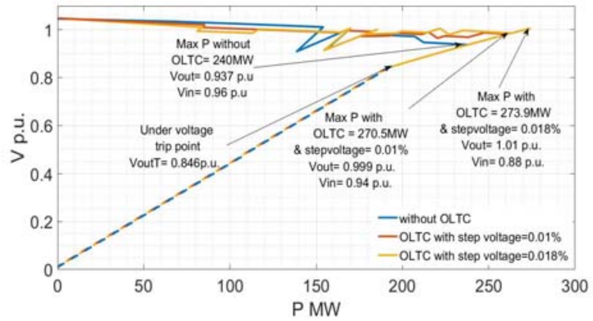

Fig. 5. The effect derived from an increase in the step voltage

Methods for improving the OLTC performance

P-V curves were obtained from MATLAB Simulink, to demonstrate the effect of each method, on the Nineveh power system grid, portrayed in Fig. 1. The normal readings of the OLTC for the system, at the OLTC real settings and standards, are exhibited in Table 3.

Table 3. OLTC standards in the Nineveh power system grid

OLTC specifications	
Rated MVA	300
Rated voltages (kV)	400/138.6
Transformer impedance (Ω)	0.006+j0.185
The total number of steps	21
The type	Mech. Tap changer
The step of the voltage	1%
The delay time (s)	15
The switching time (s)	5
Tap changer location	Primary side
The setting of the over-load relay (MW)	>= 288.0
The setting of the under-voltage relay (p.u.)	<= 0.8460

1 - Increasing the step voltage method

The OLTC step voltage is determined by the number of coil turns added in each step of the tap. Typically, the step voltage ranges between 1% and 2.5%. In a situation where the step voltage is high, OLTC will successfully maintain the rated value with a fewer number of steps. This will serve to enhance the degree of reliability and increase the bandwidth of OLTC [16].

For the system in Fig. 1, with a variable load and a variable source, the value of the factory set of the step voltage is 1%. Table 4 exhibits the system readings at that value.

Table 4. The standards value of Nineveh OLTC

Standards value of Nineveh OLTC	
P_{max} (MW)	270.50
V_{B2} (V_{in}) at collapse point(p.u.)	0.9400
V_{B7} (V_{out}) at collapse point(p.u.)	0.9990
V_{B2} (V_{in}) at under voltage trip point(p.u.)	0.7800
P (MW) at the point of trip	190.00

Table 5. Comparison between the systems with step voltage 1% and step voltage 1.8%

	step voltage =1%	step voltage =1.8%
P_{max} (MW)	270.50	273.90
V_{B2} (V_{in}) at collapse point (p.u.)	0.9400	0.8800
V_{B7} (V_{out}) at collapse point (p.u.)	0.9990	1.0100
V_{B2} (V_{in}) at under voltage trip point (p.u.)	0.7800	0.7200
P (MW) at the point of the trip	190.0	191.0

When the step voltage increased to 1.8%, an improvement was discerned in the performance of the OLTC, as depicted in Fig. 5, where the value of P max = 273.9 MW, Vout = 1.01 p.u., Vin = 0.88 p.u., P trip point = 191 MW, and Vin at trip point = 0.72 p.u. The difference between systems with step voltage 1%, and step voltage 1.8%, is made obvious in Table 5.

2 – Increasing the number of steps method

The number of OLTC steps is dependent on the number of coil parts, which the tap terminals are taken from. An increase, in the number of steps, enhances the capacity of OLTC, to continue with the voltage regulation process, in a situation where the voltage drop escalates with time. The number of OLTC steps can range from 15 to 33 [16]. The OLTC model in Fig. 1 features 21 steps. At that number of steps, the system readings are as shown in Table 4. With an increase in the number of steps to 31, the P max = 270.5MW, Vout = 1 p.u., Vin = 0.94 p.u., P trip = 189.2 MW, and Vin at trip point = 0.74 p.u.

A reduction in the number of steps to 17, brings about a dip in the OLTC performance, as evidenced by P max = 266.4 MW, Vout = 0.992 p.u., Vin = 0.96 p.u., P trip = 192.3 MW, and Vin at trip point = 0.80 p.u.

The effects stemming from changes in the number of steps, can be observed in Fig. 6, while Table 6 portrays a comparison between the three different situations.

Table 6. System readings for different number of steps

	At 17 step	At 21 step	At 31 step
P_{max} (MW)	266.40	270.50	270.50
V_{B2} (V_{in}) at collapse point (p.u.)	0.9600	0.9400	0.9400
V_{B7} (V_{out}) at collapse point (p.u.)	0.9920	0.9990	1.0000
V_{B2} (V_{in}) at under voltage trip point (p.u.)	0.8000	0.7800	0.7400
P (MW) at the point of the trip	192.30	190.00	189.20

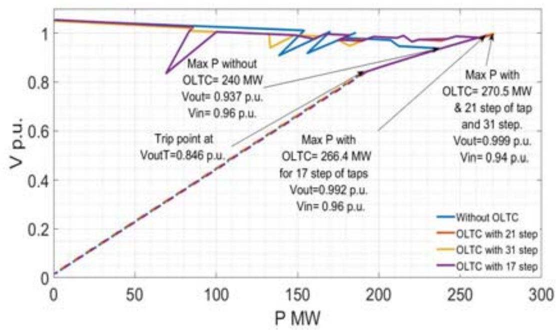

Fig. 6. the effect of changes in voltage step numbers changes

3 - Reducing the delay time method

Operators can set the delay time in the OLTC controller, to prevent the OLTC from responding to fleeting transient disturbances, including those associated to motor starting or switching. However, it should be noted, that a delay time set at too high a value, will have a negative effect on the OLTC performance. The delay time can be set at a value ranging between 10 to 120 seconds, depending on the load type [16]. For the system depicted Fig. 1, the system readings for the delay time of 15 seconds, can be observed in Table 4. The longer delay time of 25 seconds led to P max = 265.3 MW, Vout = 0.99 p.u., Vin = 0.94, P trip = 190 MW, and Vin at trip point = 0.78p.u.

The effect of delay time change is shown in Fig. 7, while a comparison between two systems, with different delay times in the OLTC controller, is depicted in Table 7.

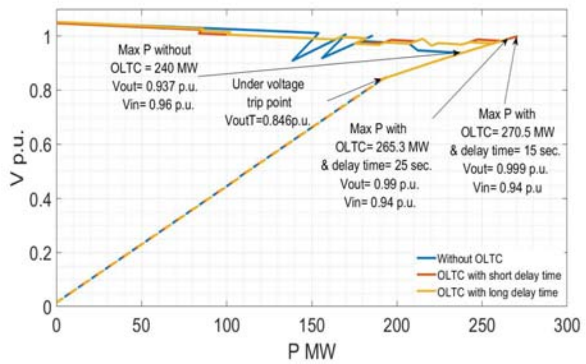

Fig. 7. The effect of changing the delay time of OLTC.

Table 7. Comparison between system OLTCs with different delay times

	At delay time =15 s	At delay time = 25 s
P_{max} (MW)	270.50	265.30
V_{B2} (V_{in}) at collapse point (p.u.)	0.9400	0.9400
V_{B7} (V_{out}) at collapse point (p.u.)	0.9990	0.9990
V_{B2} (V_{in}) at under voltage trip point (p.u.)	0.7800	0.7800
P (MW) at the point of the trip	190.0	190.0

4 – Shortening the switching time method

Generally, the switching time is associated to the type of tap changing procedure employed, and the tap type. A reduction in the switching time never fails to provide a positive effect. The time taken up between the controller decision, and the tap execution, ranges from 5 seconds to 120 seconds, depending on the tap type involved [14]. For the system depicted in Fig. 1, with the switching time of 5 seconds, the system readings are as shown in Table 4. While at the switching time of 25 seconds, the P_{max} = 255.5 MW, Vout = 0.97 p.u., Vin = 0.94 p.u., P trip = 190 MW, and Vin = 0.78, as shown in Fig. 8. A comparison between two systems, with different OLTC switching times, is portrayed in Table 8.

Table 8. Comparison between OLTCs with different switching times

	At switching time = 5 s	At switching time = 25 s
P_{max} (MW)	270.50	255.50
V_{B2} (V_{in}) at collapse point (p.u.)	0.9400	0.9600
V_{B7} (V_{out}) at collapse point (p.u.)	0.9990	0.9700
V_{B2} (V_{in}) at under voltage trip point (p.u.)	0.7800	0.7800
P (MW) at the point of the trip	190.00	190.00

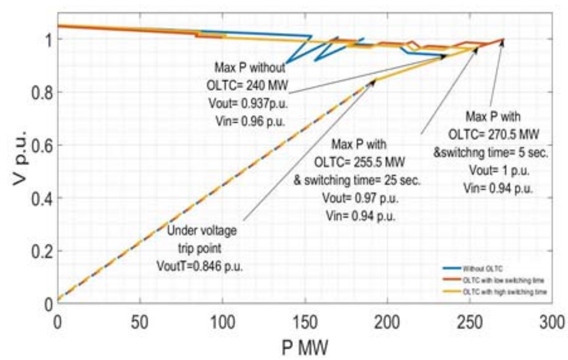

Fig. 8. OLTC switching time change effects

Conclusion

In the context of power systems, the numerous causes of voltage decline, and the extensive effects of disturbances on voltage stability, have led to the development of many schemes, aimed at controlling the system voltage, and extending the stability region. Among such schemes is OLTC. While OLTC contributes towards improvements in a power system, in terms of voltage stability, the reverse action associated to OLTC, can also lead to a collapse of this system. The value of *n*, in a power system, can be harnessed to maintain its stability.

The modeling of the Nineveh power system in MATLAB Simulink, revealed the superiority of a system with OLTC, over a system without OLTC. The modeling exercise conducted on the Nineveh power system, also involved the examination of several methods to improve the OLTC2 performance, in terms of voltage control, power transference, and voltage stability.

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REFERENCES

[1] P. L. Swe, W. Swe, and K. M. Lin, "Effects of tap changing transformer and shunt capacitor on voltage stability enhancement of transmission networks," *World Acad. Sci. Eng. Technol.*, vol. 51, no. October, pp. 555–558, 2011.
[2] D. Ahmed Nasser B. Alsammak, "Optimal Power Flow Solution with Maximum Voltage Stability," *AL-Rafdain Engineering Journal (AREJ)*, vol. 19, no. 6. pp. 40–53, 2011, doi: 10.33899/rengj.2011.26606.
[3] M. Kay and T. Khaing, "Co-operation of On-Load Tap Changing Transformer and Shunt Capacitor for Power Quality Improvement in Large Industrial Load," no. 3, 2013.
[4] G. Deb, K. Chakraborty, and S. Deb, "Voltage stability analysis using reactive power loading as indicator and its improvement by FACTS device," *1st IEEE Int. Conf. Power Electron. Intell. Control Energy Syst. ICPEICES 2016*, pp. 1–5, 2016, doi: 10.1109/ICPEICES.2016.7853108.
[5] "Voltage Control of Distribution Systems using Electronic OLTC," 2018, pp. 845–849, doi: 978-1-5386-6654-8/18/$31.00 ©2018 IEEE.
[6] I. Tanmay Tewari, Abheejeet Mohapatra, Member, IEEE, Sandeep Anand, Senior Member, "Coordinated Control of OLTC and Energy Storage for Voltage Regulation in Distribution Network with High PV Penetration." pp. 1–11, 2020, doi: 10.1109/TSTE.2020.2991017.
[7] N. Tshivhase, A. N. Hasan, and T. Shongwe, "A Fault Level-

Based System to Control Voltage and Enhance Power Factor Through an On-Load Tap Changer and Distributed Generators,” *IEEE Access*, vol. 9, pp. 34023–34039, 2021, doi: 10.1109/ACCESS.2021.3061622.
[8] D. Research and N. Qin, “Springer Theses Recognizing Outstanding Ph Voltage Control in the Future Power Transmission Systems.” 2018, [Online]. Available: http://www.springer.com/series/8790.
[9] C. Gao, “Voltage Control in Distribution Networks using On-Load Tap Changer Transformers UnivBath_PhD_2013_C_Gao.pdf.” pp. 1–242, 2013.
[10] J. Faiz and B. Siahkolah, “Electronic Tap-changer for Distribution Transformers,” *Power Systems*, vol. 2. 2011, doi: 10.1007/978-3-642-19911-0.
[11] S. and Y. H. M. Abu Ghurah1, 2, M. K. A. Kamarudin1,*, N. A. Wahab1, R. Umar1, N. A. F. Nik Wan1, H. Juahir1, M. B. Gasim1, A. R. Hassan1, F. Lananan1, A. F. Ireana Yusra1, “Special issue. Special issue,” *J. Fundam. Appl. Sci.*, vol. 4, no. 1, pp. 9–10, 2018, [Online]. Available: http://dx.doi.org/10.4314/jfas.v10i1s.7.
[12] C. R. Sarimuthu, V. K. Ramachandaramurthy, K. R. Agileswari, and H. Mokhlis, “A review on voltage control methods using on-load tap changer transformers for networks with renewable energy sources,” *Renew. Sustain. Energy Rev.*, vol. 62, pp. 1154–1161, 2016, doi: 10.1016/j.rser.2016.05.016.
[13] E. M. M. C. O. Chang, “Artificial Neural Network for the Control Mechanism of OLTC on the.pdf.” pp. 342–350, 2022, doi: 10.5370/KIEE.2022.71.2.342.
[14] R. Małkowski, M. Izdebski, and P. Miller, “Adaptive algorithm of a tap-changer controller of the power transformer supplying the radial network reducing the risk of voltage collapse,” *Energies*, vol. 13, no. 20, 2020, doi: 10.3390/en13205403.
-
[15] L. Choukri, H. Chekenbah, R. Lasri, M. Bouhorma, and Y. Maataoui, “On-load tap-changer control by a fuzzy logic controller,” in *Proceedings of 2019 IEEE World Conference on Complex Systems, WCCS 2019*, 2019, p. 6, doi: 10.1109/ICoCS.2019.8930778.
[16] T. X. Zhu, S. K. Tso, and K. L. Lo, “An investigation into the OLTC effects on voltage collapse,” *IEEE Trans. Power Syst.*, vol. 15, no. 2, pp. 515–521, May 2000, doi: 10.1109/59.867134.
[17] Hi. Ohtsuki, A. Yokoyama, and Y. Sekine, “Reverse Action Of On-Load Tap Changer In Association With Voltage Collapse,” *IEEE Transactions on Power Systems*, vol. 6, no. 1. pp. 300–306, 1991, doi: 10.1109/59.131076.
[18] C. C. Liu and K. T. Vu, “Analysis of Tap-Changer Dynamics and Construction of Voltage Stability Regions,” *IEEE Transactions on Circuits and Systems*, vol. 36, no. 4. pp. 575–590, 1989, doi: 10.1109/31.92890.
[19] P. Thannimalai, R. R. Raman, P. Nair, and K. Nithiyananthan, “Voltage stability analysis and stability improvement of power system,” *Int. J. Electr. Comput. Eng.*, vol. 5, no. 2, pp. 189–197, 2015, doi: 10.11591/ijece.v5i2.pp189-197.
[20] B. M. Weedy, B. J. Cory, N. Jenkins, J. B. Ekanayake, and G. Strbac, “Electric Power Systems Fifth Edition,” *Electric Renewable Energy Systems*. pp. 403–456, 2015.
[21] K. S. Gallant, “The Protective Principle,” *International Criminal Jurisdiction*. pp. 409–440, 2022, doi: 10.1093/oso/9780199941476.003.0006.
[22] wye, “TRANSFORMERREVERSE ACTION OF ON-LOAD TAP-CHANGER,” *Sag 2001*, vol. 21, no. 3, pp. 295–316, 2001.