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A Review on Power System Voltage Stability with Limitation of an On Load Tap Changing Transformer

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ABSTRACT

Voltage stability of power systems reflects challenges to the power system operators due to its effect on the power systems components performances. Therefore, many solutions were invented in order to keep the systems within the voltage stability accepted limits. Because of the huge expansion of the power grids and the different loads natures on the grids, many techniques and solutions are used. The On Load Tap Changing Transformer (OLTC) was one of those techniques. In this paper, a review of past works that deal with the voltage stability limits, voltage stability improvement ways, OLTC types, the OLTC reverse action, and OLTC effect on voltage stability, in addition to several ways that make the OLTC work better. are discussed. The paper also sheds the light on the possible ways that may be employed to prevent the OLTC reverse action.

Keywords:

Voltage stability; OLTC; transformer reverse action; voltage collapse; performances improvement

1. INTRODUCTION

Power system voltage instability problem was the biggest problem that the power systems suffer from all over the last years until todays[1]. Therefore, it was the focus of attentions for many of the researchers[2]. When a disturbance occurs, the system voltage affected with it and the voltage value may get up or down[3].

The reactive power directly affects the voltage stability, and its value must be under control, or else, the system voltage will go to the instability area[4]. The reactive power increases the effect of the system loss, voltage value, current limitation, and the over heat of the system devises[5].

Usually, the system voltage drops when the load increases to a high limit or due to a fault in one of the grid buses. If the system voltage continues with its dropping without compensating, the system will get into voltage instability region and starting with falling down till the collapse occurs[6].

Therefore, the occasion requires to find different ways for keeping the systems stable and to drag the system back to stability region after disturbances. Many techniques are used to improve the voltage stability of the power systems, like, using FACTS devices[7], shunt capacitance[8], installing generation plants on distribution grids[9], loads shedding[10], network voltage reinforcement[11], in addition to using the OLTCs[12].

The OLTC is one of the most popular voltage regulation devices that are used, having special features that differentiate it from the other devices[13]. One of those features is that the OLTC during the regulation process affects the voltage of all the system busses[14], while most of the other devices affect the voltage of a specified bus only[15]. In addition, the cost of adding a tap changer to the power transformer is low compared with adding one of the other devices to the grid[16].

Although the OLTC affecting positively on the system voltage by restoring the value of the system voltage after the long term disturbances, sometimes it may be the cause of power system voltage collapse by making the voltage falling down[17]. That phenomenon is called the OLTC reverse action[18].

In some of the power systems, there are limits of using the OLTC in specified grids, especially when the nature of the system component is incompatible with the OLTC working principles, like when the system has a generation source on the OLTC secondary side. In this case, the direction of power flow may be in an opposite direction and that may be confused the OLTC controller[19].

The OLTC performances in the power systems depend on their factory specifications and the controller unit settings. Because the OLTC performance in the power systems is related with its response speed and with the regulation bandwidth, which is related with the OLTC factory specifications and the controller unit settings[20].

This paper aims to review the previuos works on voltage stability of power systems and its improving possible ways, OLTC types, the OLTC effect on the voltage stability of the power systems, the reverse action phenomenon and some of the OLTC controller control techniques.

2. VOLTAGE STABILITY OF POWER SYSTEMS

Any power system could be a stable system if and only if it could go back to the voltage stability area after it have been subjected to disturbance and dodges the collapse[21]. Voltage instability is a dynamic process and its effect appears after a time and usually happens after the large disturbances[22].

When a disturbance occurs, the system voltage is affected directly. If the disturbance was a short term. the system will generally be able to restore the value of its voltage. However, if the disturbance was a long term, the system will need a suitable regulation process to restore the value of voltage and to stay in the voltage stability region. Largely, the power systems suffers from the hardness of going back to stability region after the long-term disturbance[23].

The voltage stability in any power system is important because the stable system will work with the minimum value of loss[24], [25], minimum operation costs, maximum transferred power, and long devises life[26].

Voltage stability of any power system or of any bus in the power system can be determined through the voltage stability indices[27]. The voltage stability region can be found by several methods[22].

2.1. Voltage Stability Indices

There are many indices to determine the weak bus in power system. They are used as an indicator of voltage instability in the power systems to prevent the collapse by the fast treatment to the voltage level. A review of some works that deals with those indices is summarized below for the system in Figure (1).

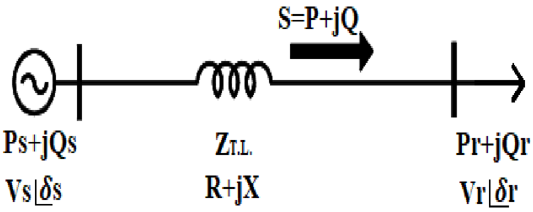

Fig. 1 Single line diagram for an equivalent circuit of a power system.

2.1.1. Index of line stability (L_{index})[28]

The index of line stability (L_{index}) has been formed depending on the idea of power transfer through a single transmission line like in Figure (1). The form is shown in equation (1) below.

$$L_{index} = \frac{4\,X\,Q_r}{(V_S \sin(\theta - \delta))^2} \quad \text{…… (1)}$$

For the system or transmission line to be stable, the L_{index} should be close to one, and not over. If the value of L_{index} is below one, then the system is stable.

2.1.2. Index of fast voltage stability (FVSI)[29]

The Index of fast voltage stability (FVSI) depends on the concepts of the power flow through the transmission line. For the system in Figure (1), the index can be calculated as in equation (2).

$$\text{FVSI}_{index} = \frac{4\,Z_{T.L.}^2\,Q_r}{V_S^2\,X} \quad \text{…... (2)}$$

If the value of FVSI is below or close to one, the system will be stable. Otherwise, it will be un stable, which means that one of the system busses voltages will falling down.

2.1.3. Index of novel line stability (NLSI)[30]

For a two-bus power system like in Figure (1), the formulation of the novel lines stability index will be as in equation (3):

$$NLSI = \frac{R\,P_r + X\,Q_r}{0.25\,V_S^2} \quad \text{…… (3)}$$

The system will be stable when the value of NLSI will be less than or equal to one. Otherwise, the system or bus voltage will be unstable.

2.1.4. Index of voltage collapse proximity (VCPI)[31]

This indicator depends on the maximum power delivered through the transmission line to the reserving end, but with different formulation like in equation (4). The value of $P_{r(max)}$ can be found from equation (5).

$$VCPI = \frac{P_r}{P_{r(max)}} \quad \text{...... (4)}$$

$$P_{r(max)} = \frac{(V_s)^2 \cos\theta}{Z_s 4\cos^2(\theta - \emptyset/2)} \quad \text{...... (5)}$$

At no load, the VCPI index will be zero. When the power starts with flowing through the transmission line, the value of the index will increase, till it reaches a value of more than one, and then the collapse will occur.

2.1.5. Index of reactive power sensitivity (IRPS)[32], [33]

This indicator depends on the newton-Raphson load flow analyses, where the general equation is:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix} j1 & j2\\ j3 & j4\end{bmatrix} \times \begin{bmatrix}\Delta\partial\\ \Delta|V|\end{bmatrix} \quad \text{...... (6)}$$

The diagonal elements of the matrix j4 is used to indicate the sensitivity of the system for a certain bus like in equation (7) and (8). The bus that has the maximum dQ/dV is the stronger bus in the power system.

$$\frac{\partial Q_s}{\partial |V_S|} = -2|V_S||Y_{SS}|sin\theta_{ss} - \sum_{r\neq s}|V_r||Y_{sr}|\sin(\theta_{sr} - \delta_s + \delta_r) \quad \text{...... (7)}$$

$$\frac{\partial Q_s}{\partial |V_S|} = -|V_S||Y_{Sr}|\sin(\theta_{sr} - \delta_s + \delta_r) \quad \text{...... (8)}$$

Table (1) illustrates the comparison between the above-five indicators which are used to indicate the systems or buses stability.

Table (1). A comparison between the five deferent voltage stability indicators.

Research year	Indicator symbol	Indicator equation	The value for stability	The value for instability
1998	L_{index}	$L_{index} = \frac{4\,X\,Q_r}{(V_s \sin(\theta - \delta))^2}$	≤ 1 (close to 1)	>1
2002	FVSI	$FVSI_{index} = \frac{4\,Z^2\,Q_r}{V_s^2\,X}$	≤ 1 (close to 1)	>1
2007	NLSI	$NLSI_{index} = \frac{R\,P_r + X\,Q_r}{0.25\,V_s^2}$	≤ 1 (close to 1)	>1
1998	VCPI	$VCPI = \frac{P_r}{P_{r(max)}}$	≤ 1	>1
2007 and 2016	IRPS	$\frac{\partial Q_s}{\partial |V_S|} = -2|V_S||Y_{SS}|sin\theta_{ss} - \sum_{r\neq s}|V_r||Y_{sr}|\sin(\theta_{sr} - \delta_s + \delta_r)$	The bus has maximum dQ/dV	The bus has minimum dQ/dV

2.2. Voltage Stability Region Indicate Methods[22]

There are many methods to find the stability region of power system and discover the collapse moment. Load flow analyses can be used to find the system ability to force the load by determining the base power and voltage.

The P-V curve and the Q-V curve can also be used to obtain the stability region of power systems in steady state case.

The load flow programs are used for the approximate analyses because they take the readings in specified moment and make the analyses based on those readings. The P-V and Q-V curves are, however, used for the conceptual analyses for voltage stability studies and finding the collapse point for the power systems.

To draw a P-V curve for example, several power and voltage readings are taken at the same time. Therefore, the meeting points of each pair of readings are marked to make up the P-V curve.

2.2.1. P-V curve and the voltage stability

On the P-V curve, for each value of power readings, there are two voltage values. One of them is located under the critical point, and the other is over the critical point. For the lower point, the value of current will be so high if compared with the upper point. Because they have the same power level but a different voltage value, the point of low voltage will try to compensate the voltage drop by increasing the current value to performs the same power value[34].

If the operating point lies over the critical point on the P-V curve after disturbances occurs, at that point, the system may restore its voltage value to the one prior to the disturbance. If the operating point gets down the critical point, the ability of collapse will be large, and the system will collapse faster. This is because, at that point, the value of voltage will be under the critical value of the system[35].(see Figure (2)).

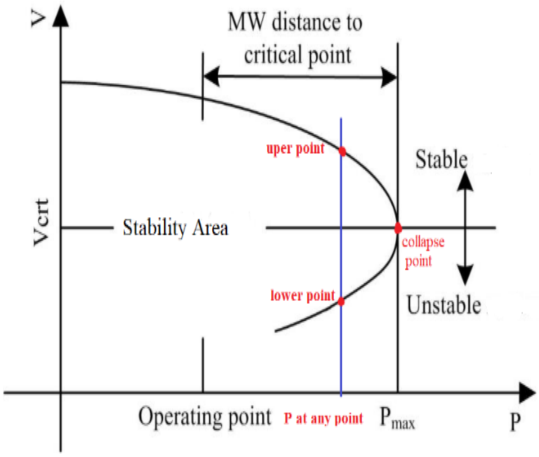

Fig. 2 The stability area on and the collapse point.

3. OLTC TRANSFORMER[36]

OLTC is one of the important devices in power system grids. It differs from the usual power transformers by its ability to regulate the power system voltage without disconnecting the load.

The OLTC regulates the voltage level of power systems by changing the number of coil turns of one of the transformer coils. Thus, the transformer turns ratio.

If the turn ratio process is done when the load is disconnected, the transformer will be called (off load tap changing transformer). Otherwise, if the tap changing process is done without disconnecting the load, the transformer is called the (on load tap changing transformer).

The OLTC turn ratio changing is done by the tap changer unit, which consists of the extra winding, the control unit, and the switching mechanism.

3.1. The Extra Windings[37]

The extra windings may be called the auxiliary tap windings, or merely tap windings. It consists of many of small groups of windings. Each one of those windings causes an increase in the output voltage by a certain value. The tap windings groups are placed on the same core, having the same number of turns. Each one of the tap windings has a terminal to connect it with the transformer main coil by the transformer tap changer unit.

The tap windings may connect to the primary side of the power transformer or to the secondary side of the power transformer. Usually, it connects with the high voltage side coil, because of the low current in that side, and the reliability of connection mechanism due to the location of the high voltage windings placement in the outer side of the transformer coil. The real shape of the OLTC windings and the conection with the tap changer is like the one in Figure (3).

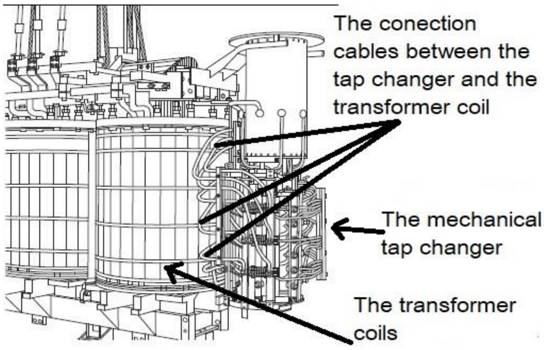

Fig. 3 The connection between the transformer windings and the tap changer.

The tap winding may be in the same case with the transformer main coils, or it may be in a separate case beside the main transformer case[38].

3.2. The Taping Mechanism[16]

The taping mechanism is referred to as the tool that connects the terminals of the main transformer coil with the certain tap terminal of the tap windings, depending on the voltage value of the transformer output.

When a voltage drop occurs, the tap changer adds more turns to the transformer coil in order to increase the transformer turn ratio. The voltage generated from the extra windings will be add to the voltage generated from the main coil of the power transformer. As a result, the output voltage will increase.

Sometimes, the power system faces a sudden increase in voltage, because of losing a large load, or due to an increasing in the distribution generation. At that time, the OLTC should reduce the value of the output voltage of the OLTC.

Taping mechanism performs an opposite connection for the taping windings. Thus, the tap changer will have the ability to decrease the value of voltage.

As a result, the transformer that has 10 parts of tap coils will have a 21-step voltage with the common point 0.

3.3. OLTC Types[16]

The OLTCs have two main types of tap changers according to the switching mechanism. The first type is the mechanical tap changer, and the second is the electronic tap changer.

3.3.1. The mechanical tap changer

The mechanical tap changer working principles depend on a group of a mechanical switches, located in a certain places. Those switches usually change their positions and moving from a position to another by a motor drive like in Figure (4). The motor takes its orders to move and stop from, the tap changing controller unit.

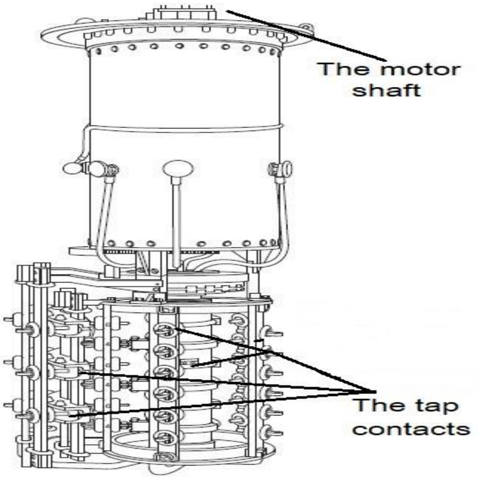

Fig. 4 The mechanical tap changer of OLTC.

3.3.2. The electronic tap changer

The electronic tap changer is doing the same job of the mechanical tap changer, but with using electronic switches. However, the electronic switches in the tap changers perform in a more reliable and flexible way in the controlling process of the power systems voltage.

3.3.3. Advantages and disadvantages of the two types of OLTC

Each of the OLTC types has advantages and disadvantages:

3.3.3.1. Advantages of using the mechanical tap changer

- Low manufacturing cost.
- The controller unit is simple.
- Good withstand at faults and transient.

3.3.3.2. Disadvantages of using the mechanical tap changer

- The spark between the contacts will spoil the transformer oil**.**
- High maintenance costs.
- Slow moving from a tap to another**.**
- High loss due to the sparks at the changing process**.**

3.3.3.3. Advantages of using the electronic tap changer

- Low maintenance costs**.**
- High response speed.
- The ability of jumping through the taps.
- It helps improve the OLTC performances due to the high switching speed.
- There are no limiting switching operations because it has no contacts.

3.3.3.4. Disadvantages of using electronic tap changer

- The electronic switches cause a voltage drop
- The electronic tap changer cost is so high compared with the mechanical type
- The electronic switches are sensitive to the high voltages

3.4. The Evaluation of The OLTC Tap Changer Technologies

The mechanical tap changer is the oldest type of tap changers and its designs are limited. The modern researches have focused on the electronic tap changers to get maximum benefits from the OLTC[39].

When the tap changer switches are replaced with an IGBT power transistor[40],or MOSFET[41], the OLTC will show an improvement in its performances if the suitable algorithm used to control the IGBTs switching[42].

The tap changer switches of the OLTC transformer can be a mix from mechanical switches and power electronic switches at the same time, in order to get benefits from the fast response of the electronic switches and the low cost of the mechanical switches. This type of OLTC called the hybrid tap changer[43].

3.5. The OLTC Control Unit

The OLTC controller is the unit that is responsible for giving the orders to the tap changer to connect one of the tap winding terminals with the main coil terminal, in the light of the transformer output voltage reading after the end of the delay time to restore the voltage value to a value equal or close to the reference voltage.

The mechanical tap changer controlling method will not considerably affect the OLTC performances, because the mechanical switches will still be working in the same sequence for all the controlling methods. Besides, the delay time in the mechanical tap changer is referred to the mechanical tools movements. In the case of the electronic tap changers, though, the controlling method of the controller unit is the leader and is the more effective part on the OLTC performances. This is because the electronic tap changer has power electronic devices, which needs to control the pulsating process of the electronic switches. Figure (5) shows a diagram for the connections of the tap changer units.

There are many studies dealing with the techniques of controlling the tap changer of the OLTC; all of which present methods of controlling to get the maximum benefits from the OLTC in the power systems[44], [45], [46], [47], [48], [49].

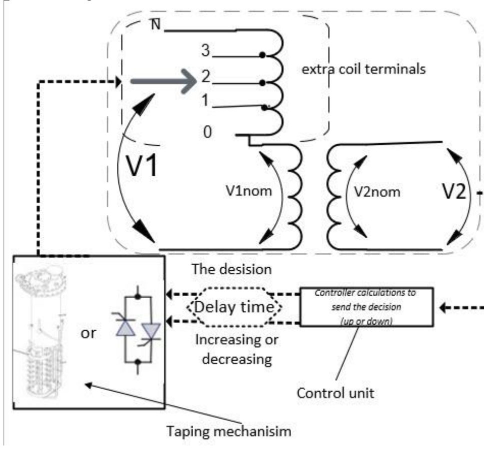

Fig. 5 The controller connection with the tap changer units.

4. OLTC EFFECT ON VOLTAGE STABILITY

The OLTC fundamental task is to regulate the power system voltage and restore the system voltage. After disturbances, the system voltage changes and may reach the instability area. Therefore, a fast treatment of system voltage should be done to prevent the system from collapse due to the hard voltage drop. Here, the positive effect of the OLTC will be obviously noticed[50].

The OLTC usually improves the power system voltage and restores the voltage value to its value after disturbance.

When the system voltage is restored, the system works properly and forwards its best performance. Therefore, when the transferred power through the OLTC increases, the system reliability increases, the lifetime of the system elements and devises will increase too without side effects. Besides, the operational and maintenance cost decreases. Sometimes, the OLTC may cause collapse due to the transformer reverse action[51].

5. OLTC REVERSE ACTION PHENOMENON

The OLTC mission in power systems is to restore the voltage after the disturbances. That means, when the OLTC output voltage is less than the reference voltage, the OLTC should increase its turn ratio to restore the voltage value. Sometimes, this increase in the turn ratio may cause a decrease in the OLTC output voltage. This phenomenon is called (OLTC reverse action phenomena).

The reverse action occurs usually on the heavy and stressed systems[52].

The phenomena of OLTC reverse action may be explained mathematically depending on the equivalent circuit of the system and the load type. On the other hand, it may be explained depending on the system reactive power.

5.1. A Review of Different Relationships For The Reverse Action Phenomenon Causes

Many studies have found a relation between the loads, transmission line impedance and OLTC turn ratio, depending on the load type and the system voltage collapse.

For the equivalent system if Figure (6), many relationships between the system components values and the reverse action can be found for different loads.

5.1.1. An impedance load (Z_{Load})[53]

If the load was an impedance load, the relationship that causes collapse to the power system due to the OLTC reverse action is:

$$E^2 Z_{Load} < 4 Z_{T.L.} V_{Load}^2 \quad \ldots\ldots (9)$$

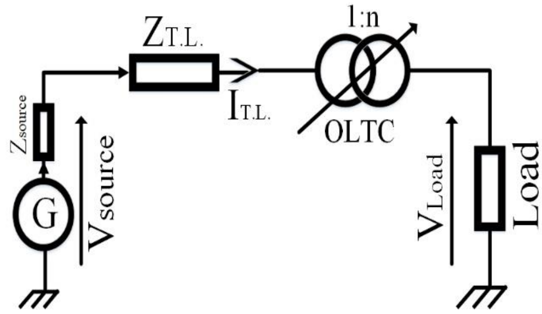

Fig. 6 Equivalent circuit of power system with OLTC.

5.1.2. A pure resistance (R)[35]

When the load was a pure resistance load and the transmission line inductance was (X), the relationship that verified collapse is:

$$R < n^2 X_{T.L.} \quad \ldots\ldots (10)$$

5.1.3. If the load was (R+jX) and the transmission line impedance (R_1+jX_1)[54]

For the same Figure (6). if the load impedance was (R+jX), and transmission line impedance was (R_1+jX_1), the value on transformer turn ratio (n) at the collapse point will be:

$$n > \left(\frac{R^2 + jX^2}{R_1^2 + jX_1^2}\right)^{0.25} \quad \ldots\ldots (11)$$

At that value of n, the reverse action will occur.

5.1.4. If the load was (Z_{Load}) and the transmission line impedance was ($Z_{T.L.}$)[55]

The relationship of the system parameters that causes collapse in this research will be:

$$Z_{Load} < n^2 Z_{T.L.} \quad \text{…… (12)}$$

To understand the differences between the above studies, a comparison in table (2) is made.

Table (2) a comparison between a different equations to find the reverse action condition.

Research year	The OLTC load type	The reverse action condition
1989	Z_{load}	$E^2 Z_{Load} < 4 Z_{T.L.} V_{Load}^2$
1991	R	$R < n^2 X$
1995	R+jX	$n > (\frac{R^2 + jX^2}{R_1^2 + jX_1^2})^{0.25}$
2001	Z_{load}	$Z_{Load} < n^2 Z_{T.L.}$

5.1.5. Numerical example:

If $Z_{T.L.}$ Was 0.6+j0.06Ω, Z_{Load} was 0.9+j0.09Ω, then, the value of n for stable system should be less than 1.224. If the value of n increases to more than 1.224, for the same transmission line and the same load, then collapse will occur.

It is noteworthy that the equations (9), (10), (11), and (12) cannot be applied to the huge power systems, and its implement is limited to the small and simple systems only[54].

5.2. Mathematical Explanation For The Reverse Action Phenomenon

When the system load increases to a high value, the load impedance (equations 9, 11, 12) or resistance (equation 10) will decrease. The load voltage will decrease as a result. Therefore, the OLTC will increase the turn ratio n. According to [52], the collapse will occur and the last equations will be achieved. At that time, the OLTC will increase the turn ratio n. and that will increase the validation of the collapse equations and make the reverse action inevitably. The OLTC will try more and more to restore the voltage of the system because the controller feedback signal is still less than the reference voltage. The extra OLTC trying to restore the voltage value will increase the voltage dropping (equations 9, 10, 11, 12); this is what is called transformer reverse action phenomenon[54].

5.3. Reactive Power Analyses for The Reverse Action Phenomenon

As mentioned in [52], when the load increased, the collapse is imminent and the value of active and reactive power will increase. The reactive power increasing causes a voltage drop and decrease. When the OLTC detects the voltage drop, it will increase the turn ratio to rise the voltage value. The turn ratio increase means that more transformer winding is at work. In addition, this means that there are more reactive power and more voltage drop for each try to restore the voltage[47].

5.4. Tap Changer Block to Prevent Reverse Action Phenomenon

The reverse action occurs when the values of the system parameters correspond to verification on the equation (9), (10), (11), and (12). Since the main cause of the reverse action is the OLTC turn ratio, some researchers studied the ability of blocking the tap changer at the right time to prevent the reverse action[56], [57].

The blocking process should be in the exact calculated time, to get the benefits of the blocking process. The delay time for blocking strategy (T_d) can be calculated from the equation (13)[58] below:

$$T_d = \frac{T_o\, d}{|V - V_r|} \quad \text{…… (13)}$$

Where d is half of the dead band of the OLTC.
V-Vr is the voltage error.
T_o is the maximum delaying time.

6. SOME SUGGESTIONS TO INCREASE THE OLTC ABILITY TO FACE THE VOLTAGE DROP AND PREVENT COLLAPSE.

The OLTC working performances depend on its control unit setting and its factory specifications. Some of these settings can be changed by the system operators, while the rest of them and the transformer specifications can only be changed during the manufacturing. Some of the OLTC settings and specifications changing can improve the OLTC ability to face the voltage drop and to prevent the collapse, like the value of the step voltage, the number of voltage steps, the tap changer switching time, and the controller delay time. The choosing of these values should be made according to system nature and the OLTC type, because some of those changes may increase the cost of the OLTC manufacturing.

- **The step voltage:** when the step voltage value increases, the OLTC will be more effective in facing the voltage drop as fast as possible. This is because it gives the OLTC the ability to arrive to the desired voltage value with the minimum number of steps. The step voltage value is a factory specification set[17].

- **The number of steps:** the number of steps depending on the number of the tap winding that could be added to the main coil of the OLTC. Increasing the number of steps will help in improving the OLTC performances. This is because it enables the OLTC to continue the regulating process for further voltage drop[17].

- **The switching time:** the switching time is the time that the tap changer requires for moving the tap from a terminal to another after the controller decision. The switching time depends on the tap changer switches type. Reducing the switching time improves the OLTC performances because the switching time is a wasted time[59]. Many of the modern researches focus on the switching types and switching control methods in order to reduce the switching time [60], [61], [62], [63].

- **The delay time:** it is the time which the controller takes before sending the changing signal to the tap changer. It is important because it prevents the OLTC from responding to the small and transient disturbances, like motors starting. Nevertheless, it should be as less as possible because its decreasing improves the OLTC regulation process by the fast response to face the voltage drop, especially when the system opposes a long-term disturbance[17].

7. THE SYNCHRONIZED OPERATION OF OLTC WITH ANOTHER VOLTAGE IMPROVEMENT STRATEGIES

All the voltage improvement strategies have disadvantages. Therefore, two or more strategies can be used at the same time to get the maximum benefits from each strategy and to avoid the disadvantages.

In [64], a capacitor banks and distribution generators are used together, controlled by (Artificial Bee Colony algorithm). The system will be more effective if the DG and the shunt capacitors get in work in the exact size and are located in the exact location. The system loss will decrease and the system will be more reliable. The used algorithm ensures that each one of the used strategies will act in the right time to minimize the costs and increase the efficiency.

In [8], the author presents a control method to manage the capacitance which should be added to the power system to compensate the reactive power flow and voltage regulation. The control method is based on an analytical solution to a non-linear system equation to analyse the voltage divergence in the studded power system. This controlling method suggestes that the capacitors should be switched off right after the OLTC regulates the voltage, because the capacitors will affect the system current. This means that the capacitors role is temporary.

In [14], the paper discusses the use of the OLTC and the shunt capacitors (SC) in the same time. The study utilizes newton Raphson method to find the weak bus in the power system. The OLTC has disadvantages, like the limited regulation range and the need to periodical maintenance. MATLAB Simulation shows the efficiency of the method.

In [12], the effect of the increase in the renewable power in the distribution power systems on the systems voltage and how it effect the voltage control process are discussed. The research deals with the effect of the storage power plants, and how its helps in voltage regulation in the power systems. It also deals with the alignment between the OLTC and the battery storage plants. The storage power plants are useful in voltage regulation, but they affect the OLTC performances due to the bi-direction power flow. The OLTC may negatively affect the battery time life. Therefore, a control process is needed to get the maximum benefits from the regulation.

8. CONCLUSION

Nowadays, the power system operation has become complex, because of the mixture of the different types of power sources and load types on the same grid. As well as the increasing in the voltage drop and the voltage collapse causes. Many technologies have been invented to regulate and control the systems voltages. Two or more technologies could be used in the same system to guaranty the voltage restoring process is done well.

Many indicators have also been invented to monitor the system stability in order to find the suitable way to keep the system stable. The most popular way is the OLTC. The OLTC positively affects the system performances, although it may cause collapse due to its reverse action. The reverse action happenes due to the compatibility of the system impedances, load value and the OLTC turn ratio, like in equations (9), (10), (11), and (12). There is a method to prevent the reverse action, that is by blocking the transformer tap changer. However, the blocking process should be done at a certain moment in order to be useful. There are several methods to improve the OLTC performer by changing some of the OLTC settings and specifications. These changes depend on the load type of the OLTC.

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مراجعة لاستقرارية فولتية نظام القدرة مع حدود تأثير محول القدرة بمغير التفريعة الحملي

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الملخص

إن استقرارية فولتية أنظمة القدرة الكهربائية تعكس التحديات التي يواجهها مشغلي الشبكات الكهربائية نظراً لتأثيرها على أداء مكونات أنظمة القدرة. لهذا السبب، تم ابتكار العديد من الحلول للحفاظ على أنظمة القدرة ضمن حدود استقرارية الفولتية المقبولة. ولكون شبكات نقل القدرة قد توسعت توسعاً هائلا، وكذلك اختلاف طبيعة الاحمال المرتبطة بالشبكات، تم استخدام هذه التقنيات والحلول. احدى هذه التقنيات هي محولة القدرة بمغير التفريعة الحملي (OLTC). في هذا البحث، مراجعة لعدة اعمال سابقة تناولت مناقشة حدود استقرارية الفولتية، طرق زيادة استقرارية الفولتية، أنواع الـ (OLTC)، رد الفعل العكسي للـ (OLTC)، وتأثير الـ (OLTC) على حدود استقرارية فولتية النظام، بعض الطرق لتحسين أداء المحول الـ (OLTC)، الى جانب ا لطرق الممكنة التي قد تستخدم لتجنب حدوث رد الفعل العكسي للمحول.

الكلمات الداله:

استقرارية الفولتية، محول القدرة بمغير التفريعة الحملي، رد الفعل العكسي للمحول، انهيار الفولتية، تحسين اداء المحول.

Appendix 1

Symbols list

The term	The symbol	The unit
On load tap changer transformer	OLTC	-----
Flexible AC Transmission System	FACTS	-----
Sending end active power	Ps	W
Sending end reactive power	Qs	Var
Receiving end active power	Pr	W
Receiving end reactive power	Qr	Var
Sending end voltage	Vs	V
Receiving end voltage	Vr	V
Transmission line impedance	$Z_{T.L.}$	Ω
Transmission line current	$I_{T.L.}$	A
Index of line stability	L_{index}	-----
Index of fast voltage stability	FVSI	-----
Index of noval line stability	NLSI	-----
Index of voltage collapse proximity	VCPI	-----
Receiving end active power	Pr	W
Receiving end maximum active power	$Pr_{(max)}$	W
Index of reactive power sensitivity	IRPS	-----
Admittance of sending end	Yss	1/Ω
Admittance of sending-receiving end	Ysr	1/Ω
Source voltage	Vsource	V
OLTC turn ratio	n	-----
Load voltage	V_{load}	V
Load impedance	Z_{load}	Ω
Equivalent circuit source voltage	E	V
Blocking delay time	Td	second
Maximum delay time	To	second
Half of the dead time	d	second
Voltage error	V-Vr	V
Distribution generator	DG	-----
Shunt capacitance	SC	-----