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Effect of OLTC Transformer on Voltage Stability Improvement

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ABSTRACT
The voltage stability is a major concern due to increase in load demand. Therefore proper planning and operation is required. For stable operation of power network extensive voltage stability analysis is very much essential. This necessity is largely due to the current trends towards system operation under stressed condition, this is because of the increase in load demand. In this paper, a method has been developed how, with the help of OLTC Transformer voltage stability can be improved and it is tested on IEEE 14 bus system. Result shows the effectiveness of the method.

Keywords: Voltage stability, Reactive Power Sensitivity, OLTC

1. INTRODUCTION

Voltage stabilization is concerned with the capability of a power system to sustain bearable voltages under normal conditions at every buses in the system and later being subdued to a disturbance.
If voltage near loads are close or similar to the pre-disturbance values, then the power system is considered to be operating at a condition of voltage stability. A power system is considered to have come into a state of voltage instability while a disruption has produced an uncontrollable & progressive decline in voltage[1]. Due to environmental and economical constants the present transmission networks are becoming more and more stressed. Voltage stability issues normally arises in extremely stressed systems. Nowadays, there is an enormous increment for the demand power hence a large interconnected power system concern to stressed conditions. This circumstances can be controlled by transmission losses reduction or by incrementing the generation. When there is a sudden increase in load, outside the permitted voltage stability limit, but the magnitude of voltage should be kept inside the limit for actual functioning of the system. Hence, voltage stability must be enhanced by controlling suitable reactive power reparation[3]. The regulation of reactive power & voltage is a significant problem in power system operation. This is because of the topological divergence between distribution and transmission systems difference have involved. This difference in voltage stability can be controlled by different methods such as by synchronous phase modifiers, shunt capacitors, shunt reactors, tap changing transformers, series capacitors, and static VAR systems (SVS). In this paper, we have dealt with On-Load Tap Changing Transformer for stabilizing the voltage in the

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power system. Taps are provided with the transformer and by changing the number of turns voltage can be changed. The presumed work is analysed using IEEE-14 bus test system.

2. ON LOAD TAP CHANGING TRANSFORMER

On-load Tap changing Transformer (OLTC) are used in such a way that the supply may not be interrupted. The device is generally but not necessarily installed inside a transformer tank along with the winding assembly and each time it is connected to high voltage. Such transformer are called tap changing transformer. This transformer consist of two main load tap changer designs which are reactance and resistance.

There are two conditions which are to be fulfilled in OLTC and they are:-

1) To avoid the damage contacts and arcing the circuit should not be damaged or broken

2) While balancing the taps no part of the winding should be short circuited. As the short circuited part of the winding may be broken or damaged.

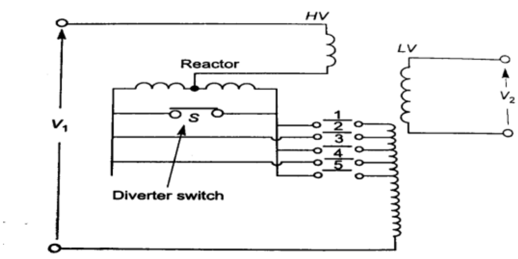

Fig 1:-On Load Tap Changer

3. EFFECT OF OLTC ON Y-BUS MATRIX

Let, a two winding transformer is connected in a line between I bus and J bus having off nominal trans ratio `a` as shown in figure. At the sending and receiving end of the line regulating transformers are provided.

The current I_s, which is flowing from the secondary of the transformer to j bus can be written from the figure. [2]

$I_s = a*I_i$ …………… (1)

Again, $I_s = yij * (V_s - V_j)$ …………….(2)

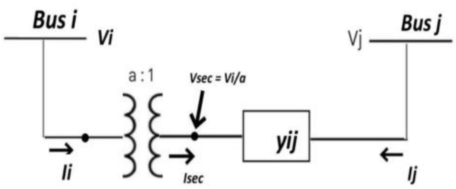

Fig 2:- A line accommodating regulating Transformer between two buses

From equation (1) & (2),

$$I_i = \frac{yij}{a}(V_s - v_j)$$

Or, $I_i = \frac{yij}{a}(\frac{Vi}{a} - V_j)$

or, $I_i = \frac{(yij)}{a^2}(V_i - aV_j)$ …………… (3)

The current I_j can be written as

$I_j = (V_j - V_s) * y_{ij} = - y_{ij} (v_i \frac{1}{a} - V_j)$

Or, $I_j = - y_{ij} \frac{1}{a} * (V_i - aV_j)$ ……………(4)

The model of pi equivalent of the system is shown in figure. In this pi model the per unit transformer admittances both series and shunt is taken into account, which are reciprocal of the transformer`s per unit impedances. Here, the two winding transformer is connected in series with an ideal transformer represented by its impedances. In this case, the shunt admittance of the line is neglected.[2]

In the figure of pi equivalent network of the system, applying KCL at i node and j node.

$I_j = (V_i - V_j) * Y_{ij} + V_i * y_{i0}$ …… (5)

$I_j = (V_j - V_i) * Y_{ij} + V_j * y_{j0}$ …….(6)

Where, new admittance of line, Y_{ij} =impedance of line, y_{ij} + series impedance of transformer

$V_i = 0$ and $V_j = 1$ is considering in the equations (5) & (3)

$I_i = -Y_{ij}$ ……………..(7)

$I_i = - \frac{yij}{a}$ ………………..(8)

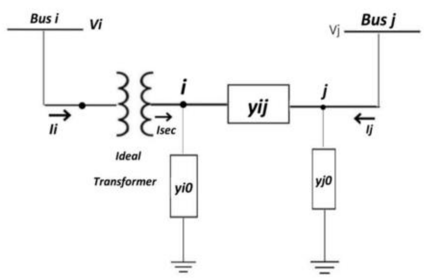

Fig 3:- Pi Equivalent circuit for regulating transformer between two buses in a line

Comparing equations (7) & (8),

$Y_{ij} = \frac{yij}{a}$ ……………(9)

Again $V_i = 0$ and $V_j = 1$ is substitute in equation (5) and (3),

$I_j = y_{j0} + Y_{ij} = y_{j0} + y_{ij}$ ………….(10)

$I_j = y_{ij}$ ………….(11)

From equations (10) and (11),

$Y_{j0} = y_{ij} \ (\frac{a-1}{a})$

The value of y_{ij} is substitute from equations (9) and (5) and comparing with (3),

$Y_{i0} = \frac{yij}{a} \ (\frac{a-1}{a})$ …………(13)

The figure is represents the equivalent diagram, Where two-winding transformer is connected in series with an ideal transformer represented by its impedances.
In this system, the elements of Y-Bus matrix can be written as

$$Y_{ii} = \frac{yij}{a} + \frac{yij(1-a)}{a2} = \frac{yij}{a^2} \quad \ldots\ldots\ldots\ldots\ (14)$$

$$Y_{ij} = \frac{yij}{a} + yij(a-1)\frac{1}{a} = y_{ij} \quad \ldots\ldots\ldots\ldots\ldots (15)$$

$$Y_{ii} = Y_{ij} = -\frac{1}{a} yij \quad \ldots\ldots\ldots\ldots (16)$$

Now, the above elements compared with Y-Bus matrix`s elements of two bus system, the Y-bus matrix is changed as because a transformer is include which as follows [2]:
1. Self-admittance of the sending end bus (or the nearest bus among the buses between which transformer is included) have to change by the term V_{ij}/a^2 in lieu of y_{ij}.
2. The self admittance of receiving end bus will remain same.[1].
3. The mutual admittance between buses which include the transformer to be changed by the term $\frac{yij}{a}$ in lieu of $-y_{ij}$.

4. REACTIVE POWER SENSITIVITY INDEX

The basic which is used in the Newton-Raphson Load Flow Analysis is as follows:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \quad \ldots(6.119)$$

Here J is the Jacobian Matrix which is consist of J_1, J_2, J_3, J_4. The reactive power sensitivity indicated by the diagonal elements of J_4.
The diagonal and off-diagonal elements of J_4:

$$\frac{\partial Qi}{\partial |Vi|} = -2 \sin\Theta ii * |Yii||Vi| - \sum_{j=} i*\sin(\Theta ij - \delta i + \delta j) * |Yij||Vi| \quad \ldots\ldots\ldots\ldots (2)$$

$$\frac{\partial Qi}{\partial |Vi|} = -2*|Yij||Vi| \sin(\Theta ij - \delta i + \delta j) \quad [J \neq i]$$

……………(3)

From equation (2) i.e. the diagonal element of j_4,we can find the value of dQ/dV of each load bus, by taking the inverse of this value we will get dV/dQ index i.e sensitivity of reactive power of any particular bus.
Reactive power sensitivity index i.e. dV/dQ index can be used for finding the strongest and weakest bus. When dV/dQ index is smallest the bus can be identified as strongest bus. On the other hand when dV/dQ index is highest the bus can be indicated as weakest bus.
Benefits of Reactive Power Sensitivity Index:
i. Reactive Power Sensitivity Indicator improves the stability of voltage of the system.
ii. Reactive power seeks to minimize the congestion of power flow.
iii. It reduces the power losses.
iv. Reactive power is essential to move active power through the transmission line.

5. RESULT AND SIMULATION

5.1.Determination of weakest bus in the system:-

The purpose of the simulation is to determine the voltage stability of multi-bus power system network. The aim of the 1st part of this work is to find out the weakest bus of the network. For this purpose we have to find out the values of dQ/dV from equation no. 18 of reactive power sensitivity index. After inversing it we found reactive power sensitivity index (dV/dQ)

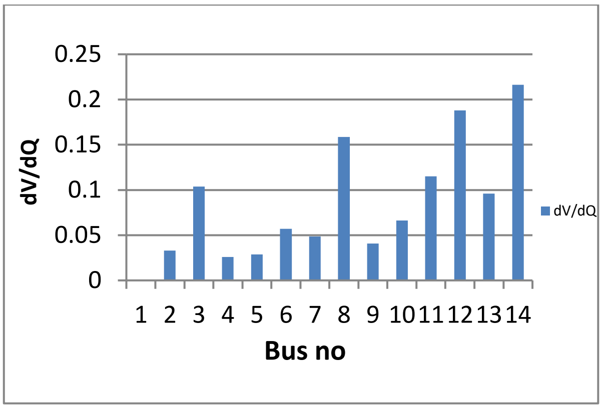

Fig. 4: dV/dQ values of each system

5.2. Plotting of P-V curve for finding out the critical values of voltage and active power:-

In the 2nd part of this work we have increased thev active power loading at the weakest-bus in steps keeping the loading of other buses at their base values. For each active power loading we have noted down. An bus voltage magnitude until the stability limit is reached. From this data we have plotted the P-V curve for bus no. 14 which is shown in fig. 5.

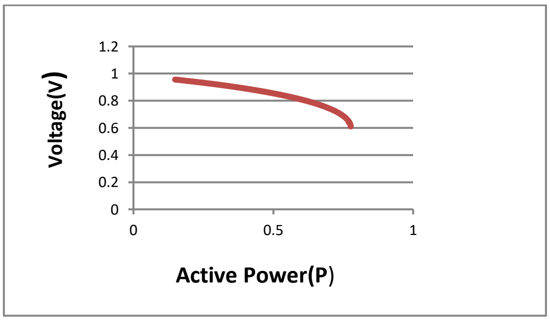

Fig. 5: P-V curve for critical values of voltage and active power

5.3. Improvement of voltage stability using OLTC:- For improving the voltage stability of the network and OLTC transformer has been installed in the lines connected with the weakest bus once at a time. In the system under study there are two lines connected with the weakest bus which are line no 17 which is connected between bus no 9 & 14 and line 20 which is connected between bus no 13 & 14.

Case 1: OLTC installed in the line no. 17:-

In this case we have installed an OLTC with tap ratio 0.9 in the line no 17 that is the line connected with the bus 9 & 14. Under this situation again active power loading has been increased in step from its base value and each corresponding voltage magnitude has been noted for the plotting of the P-V curve.

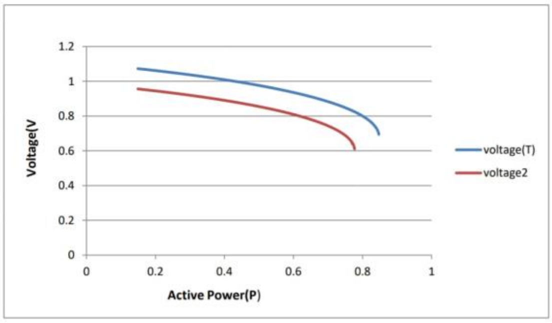

Fig 6: P-V curve for bus no 14 before & after connecting a new line form bus no 9-14

Fig. 6 shows a comparative study of the P-V curve of the weakest bus with and without OLTC. From this comparative graph it is observed that before applying OLTC the critical value of active power loading for the weakest bus was 0.777 p.u. and that of voltage magnitude is 0.61 p.u. and after applying the OLTC it is observed that both the critical values of active power loading and bus voltage magnitude has been increased to 0.847 p.u. and 0.694 p.u. respectively.

Case 2: OLTC installed in the line no 20:-

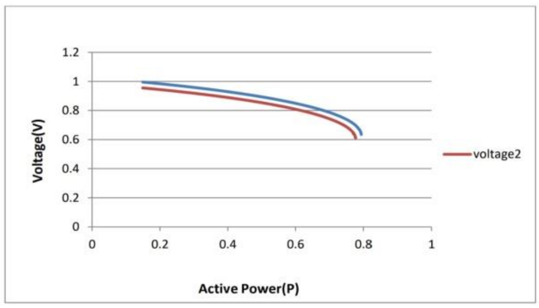

Fig 7: P-V curve for bus no 14 before & after connecting a new line from bus no 13-14

In this case the OLTC which was earlier installed in line no 17 has been removed and the same is installed in line no 20. And same procedure is described in case 1 has been repeated to obtain the P-V curve under this new condition which is shown in fig. 5 along with the P-V curve of the weakest bus without OLTC. In this case also it is observed that the critical values of voltage magnitude and active power loading has been increased due to the installation of OLTC which are Shown in table.

Transformer connected between	Load change in bus no. (i.e. Weakest bus)	Without Transformer		With Transformer		% change in	
		P Critical	V Critical	P Critical	V Critical	P Critical	V Critical
BUS 13 - 14	14	0.777	0.6104	0.790	0.6637	1.67%	8.73%
BUS 9 - 14	14	0.777	0.6104	0.847	0.6947	9.00%	13.81%

From the above table it is observed that due to the installation of OLTC in line number 17 (case 1). The percentage change in the critical values of active power loading and bus voltage magnitude is higher compare to case 2.

6. CONCLUSION

On load Tap Changing Transformer has been used in this study for improvement of stability of voltage in the power system network. In the starting of this work the weakest segment of the network has been identified. After that on load tap changing transformer has been installed to study its effect on voltage stability. It is found that when a tap changer is connected between the buses (9-14, 13-14) then critical values for active power loading and voltage magnitude has been increased significantly. The result obtained from the present study clearly indicates that the change of trans. ratio has significant impact on voltage stability.

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