International Journal of Electronics and Electrical Engineering
ISSN : 2277-7040 Volume 2 Issue 3 (March 2012)
http://www.ijecee.com/https://sites.google.com/site/ijeceejournal/

Comparison of Sensitivity and Nonlinear Optimization Methods for Transmission Network LTCs setting

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Abstract. This paper compares the sensitivity method with a proposed nonlinear optimization method for setting of transmission network load tap changers (LTCs) as a preventive action for voltage instability. The aim of preventive actions is to increase voltage stability margin. In contrast to emergency actions, preventive ones implemented when the power system is stable. Thus, in calculation of a preventive action, in addition to increase stability margin, its effects on current operating point of the system must be considered. The sensitivity method is a linearized based method that uses the sensitivity of the loadability margin with respect to tap values. In the proposed optimization method, the tap values are calculated using optimal powerflow model. Two groups of variables are used in optimization problem: one group is related to base case (current operating point) and the other is related to the voltage stability boundary. By this work, the preventive actions do not cause undesirable changes in the system current variables.

Keywords: voltage instability, Transmission network LTCs, optimization problem, sensitivity method.

1 Introduction

Voltage instability problem is one of the important concerns in power system planning and operation. The actions used to prevent voltage instability can be divided into preventive and emergency (corrective) ones. Emergency actions are applied when the system is voltage unstable. If the system is voltage stable, but the stability margin is small, preventive actions are used to move the system into a voltage-secure operating point [1]. As there is a direct relationship between loadability limit and voltage stability boundary, any actions that increase loadability limit, improve voltage stability. Also, some actions aimed for loss reduction and voltage profile improvement can increase voltage stability margin. Tap adjustment and change in capacitor susceptance and generator voltage are measures used in literatures for above mentioned objectives [2-7]. In [2-3], above actions are used in an optimization problem for the active power loss minimization in the transmission network. The objective function is to obtain a minimum value of the active power loss. Equality and inequality constraints are power flow equations and physical limits of state and control variables, respectively. In[4-5], voltage stability margin maximization is also considered. The Jacobian matrix of power flow equations and the stability index L are used to evaluate the voltage stability margin. Both of them are calculated in the system base case. So, the inequality constraints are only considered for the base case variables and the situation of variables in the voltage stability boundary is not concerned. In [6-7], the adjustment of transmission network LTCs has been made using sensitivity analysis. The aim is to maximize voltage stability margin. The method uses the sensitivity of the loadability margin with respect to tap values. In some studies, transformer tap settings are used as an emergency action [8-9]. In emergency control, the aim is to prevent voltage collapse at an unstable system. So, the system situation in voltage stability boundary is only considered.

This paper compares the sensitivity method used in [6-7] with a proposed nonlinear optimization method for optimal setting of transmission network LTCs as a preventive action. So, an optimization problem is formulated with two groups of variables. One group is related to the base case and the other is related to the voltage stability boundary. By this work, it is possible to use different constraints in the base case and voltage stability boundary.

2. The proposed optimization method

To determine the optimal tap values in transmission network LTCs, an optimization problem is formulated. The aim is to maximize the system voltage stability margin. As when the system loads are voltage-dependent type, the voltage stability boundary coincides with the loadability limit [10], the objective function is:

$$\max(\lambda) \tag{1}$$

where λ is loading factor. The constraints and variables are divided into two groups. The constraints and variables related to the base case and the ones used inthe voltage stability boundary. Hereafter, the variables related to the base case and voltage stability boundary are represented by superscripts "n" and "c", respectively. The variables without above marks have the same values in two situations, such as the tap values determined in the base case to extend the voltage stability limit. For a N bus system that in which N_{PQ} and N_{PV} are the number of PQ and PV buses, respectively, the constraints can be formulated as follows:

1.2 The constraints related to the base case

Equality constraints are load flow equations, as follows:

$$P_{Gi}^{n} - P_{Li}^{n} = \sum_{j=1}^{N} V_i^n V_j^n Y_{ij} \cos\left(\delta_i^n - \delta_j^n - \theta_{ij}\right) \quad i \in N_{PV} + N_{PQ} \tag{2}$$

$$-Q_{Li}^{n} = \sum_{j=1}^{N} V_i^n V_j^n Y_{ij} \sin\left(\delta_i^n - \delta_j^n - \theta_{ij}\right) \quad i \in N_{PQ} \tag{3}$$

where P_{Gi}^n, P_{Li}^n and Q_{Li}^n are the generated active power, the demanded active power and the demanded reactive power in bus i, respectively. Y_{ij} and θ_{ij} are the magnitude and angle of the elements of the system admittance matrix. They are functions of the tap values in transmission network LTCs. Inequality constraints are as follows:

$$V_{min,i} \le V_i^n \le V_{max,i} \quad i \in N_{PQ} \tag{4}$$

$$Q_{min,i} \le Q_{Gi}^n \le Q_{max,i} \quad i \in N_{PV} + 1 \tag{5}$$

$$NT_{min,i} \le NT_i \le NT_{max,i} \quad i = 1, \cdots, K \tag{6}$$

where Q_{Gi} is the generated active power in bus i, and NT_i is the tap value in transformer i. K is the number of transformers.

2-2) The constraints related to the voltage stability boundary

Equations (2) and (3) are changed in the voltage stability boundary as follows:

$$\lambda P_{Gi}^{n} - \lambda P_{Li}^{n} = \sum_{j=1}^{N} V_i^c V_j^c Y_{ij} \cos\left(\delta_i^c - \delta_j^c - \theta_{ij}\right) \quad i \in N_{PV} + N_{PQ} \tag{7}$$

$$-\lambda Q_{Li}^{n} = \sum_{j=1}^{N} V_i^c V_j^c Y_{ij} \sin\left(\delta_i^c - \delta_j^c - \theta_{ij}\right) \qquad i \in N_{PQ} \tag{8}$$

Loads and generations are increased using loading factor λ to reach the voltage stability boundary. Inequality constraint (5) is changed as follow:

$$Q_{min,i} \le Q_{Gi}^{c} \le Q_{max,i} \quad i \in N_{PV} + 1 \tag{9}$$

3. Sensitivity method

The following steps are done to maximize the loadability limit using sensitivity method:

1) Compute the value of λ^* (loading factor in loadability limit) using continuation power flow method.
2) Modify the tap values along the direction indicated by the sensitivities of the loadability limit with respect to tap values (These sensitivities are calculated using the method described in [6]**)**.
3) If the loadability limit is increased, continue as in step 2.
4) The steps continue until an optimum value for the taps is found, or all taps reach their limits, or the voltages of the base case with the calculated taps exceed the maximum or minimum permissible values.

Table 1 shows the tap values how are changed based on the magnitude of the sensitivities. In this table, $|\Delta NT_i|$ and $|S_i|$ are the magnitude of change in tap i and the corresponding sensitivity, respectively.

Table 1. How to change the tap values based on the magnitude of sensitivities

$\lvert S_i \rvert$	0-0.3	0.3-1	1-1.5	1.5-2
$\lvert \Delta NT_i \rvert$	0.01	0.02	0.03	0.04

4. Simulation and results

To simulate the proposed method, the IEEE 14 bus test system is used (Fig.1). In this system, there are 3 transformers with tap changer. Buses 1 and 2 are slack and PV bus, respectively. Three synchronous condensers are connected at buses 3, 6 and 8, so these buses are also PV bus with zero active power generation. The area consisting of the buses 9, 10, 11, 12, 13 and 14 is load region that for increasing of the voltage stability margin, the tap values must so be adjusted that more active and, in particular, reactive power can be transmitted to this region. Optimal tap values depend on active and reactive powers flowing through different lines and maximum and minimum permissible values of the voltages at PQ buses. To show these dependencies, some various cases are simulated.

Case 1: The load and generation at each bus in base case are as used in [11]. The voltage magnitude at generators and synchronous condensers is 1p.u. The permissible range for voltage variations at load buses is between 0.95 to 1.05p.u. for base case. The tap values can be changed between 0.9 to 1.1.

The value of λ^* and optimal tap values calculated using the proposed optimization method are listed in Table 2. Low value of NT_3 causes the voltage magnitude at buses 4 and 5 to increase. To enhance the maximum transferable power to the load region, the voltage magnitude at buses 7 and 9 must be increased. This can be done by the increase in the voltage magnitude at bus 5 or by the increase in NT_1 and NT_2. The former is more effective because this decreases the transmission line losses.

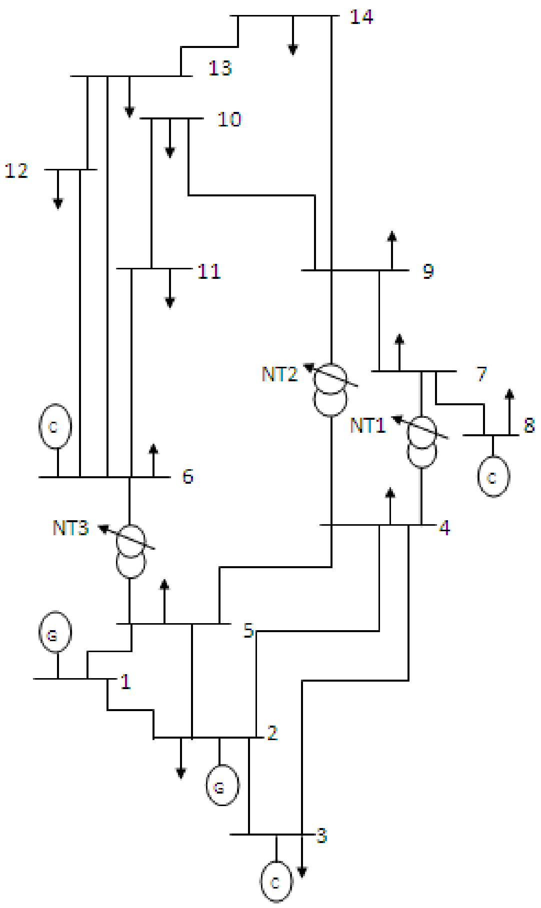

Fig. 1 The IEEE 14 bus test system

Table 2. λ^* and optimal tap values in case 1

NT_1	NT_2	NT_3	λ^*
1.02	1.043	0.9	3.68

The direction of tap changes in sensitivity method is given in Table 3. The sensitivities of the loadability limit with respect to NT_3 is much more than the others. The magnitude of changes has been determined based on the values in Table 1. It can be seen that in this case, λ^* obtained by sensitivity and optimization methods are the same.

Table 3. The direction of tap changes in the sensitivity method for case 1

iter	NT_1	NT_2	NT_3	λ^*
0	1.04	1.04	1	3.584
1	1.03	1.05	0.97	3.61
2	1.02	1.04	0.94	3.637
3	1.01	1.05	0.91	3.664
4	1.02	1.04	0.9	3.674

Case 2: The permissible range for the tap values is extended to 0.8 for lower limit and 1.2 for upper limit. Other parameters and variables are as the same as case 1.

The values of λ^* and optimal tap values determined using the proposed optimization method are shown in Table 4. NT_3 lies in the minimum permissible value. Because of the decrease in NT_3, λ^* has increased.

Table 4. λ^* and optimal tap values in case 2

NT_1	NT_2	NT_3	λ^*
1.02	1.034	0.8	3.782

The direction of tap changes in sensitivity method is given in Table 5.It can be seen that λ^* obtained by sensitivity and optimization methods are almost equal.

Case3: The permissible range for the reactive power generation at PV buses is limited to -1p.u. for lower limit and 1p.u. for upper limit. In this case, loadability is limited because of reaching the reactive power generation limits. Other parameters and variables are as the same as case 1.

The values of λ^* and optimal tap values obtained using the proposed optimization method are given in Table 6. It is shown that the value of λ^* has decreased. In the loadability limit, the reactive power generation at buses 3 and 6 simultaneously reach their limits. The value of NT_1 has been reduced to increase the share of the reactive power generated at bus 8 in supplying the load region. NT_3 does not lie in the minimum permissible value because this causes that the reactive power generated at bus 6 exceeds from their limit.

Table 5. The direction of tap changes in the sensitivity method for case 2

iter	NT_1	NT_2	NT_3	λ^*
0	1.08	1.08	1.04	3.549
1	1.07	1.07	1.01	3.575
2	1.06	1.06	0.98	3.601
3	1.05	1.05	0.95	3.627
4	1.04	1.04	0.92	3.655
5	1.03	1.03	0.9	3.674
6	1.01	1.05	0.87	3.703
7	1.02	1.04	0.84	3.732
8	1.01	1.03	0.81	3.763
9	1.02	1.02	0.8	3.774

Table 6. λ^* and optimal tap values in case 3

NT_1	NT_2	NT_3	λ^*
0.955	1.1	0. 919	1.521

Table 7 shows the direction of tap changes in sensitivity method. The steps stop because the voltage value at bus 14 reaches the lower limit (0.95p.u.) at the base case. There is a considerable difference between the value of λ^* and optimal tap values determined using the sensitivity and proposed optimization methods. The reason is that in light loaded conditions, the sensitivities of the loadability limit with respect to NT_3 is not much more than the others. So, if the values in Table 1 are used, the rate of changes in all taps is the same. Consequently, how to change the tap values based on the magnitude of sensitivities must depend on the system conditions.

Table 7. The direction of tap changes in the sensitivity method for case 3

iter	NT_1	NT_2	NT_3	λ^*
0	1.1	1.1	1.1	1.213
1	1.09	1.09	1.09	1.238
2	1.08	1.08	1.08	1.262
3	1.07	1.07	1.07	1.286
4	1.06	1.06	1.06	1.31
5	1.05	1.05	1.05	1.335
6	1.04	1.04	1.04	1.359
7	1.03	1.03	1.03	1.383

4. Conclusions

In this work, an optimization method for setting of transmission network LTCs has been proposed. The method has been compared with the sensitivity method. The simulations show that the proposed method has better results. The most important problem with the sensitivity method is that how to change the tap values based on the magnitude of sensitivities depends on the system conditions. It has been shown that the tap setting at buses close to generation region is more effective to increase loadability limit. When the reactive power generation capability is limited at PV buses, the loadability limit lies at relatively light loaded conditions. In these conditions, the difference in the magnitude of sensitivity between the effective taps and others decrease.

References

1. X. Wang, G. C. Ejebe, J. Tong, J. G. Waight, Preventive/Corrective control for voltage stability using direct interior point method, IEEE Transactions on Power Systems, Vol. 13, No. 3, Aug. 1998, pp. 878-883.

2. P. Subbaraj, P. N. Rajnarayanan, Optimal reactive power dispatch using self-adaptive real coded genetic algorithm, Electric Power Systems Research 79 (2009) 374–381.

3. M. Varadarajan, K. S. Swarup, Differential evolutionary algorithm for optimal reactive power dispatch, Electrical Power and Energy Systems 30 (2008) 435–441.

4. C. Dai, W. Chen, Y. Zhu, X. Zhang, Reactive power dispatch considering voltage stability with seeker optimization algorithm, Electric Power Systems Research 79 (2009) 1462-1471.

5. D. Devaraj, J. P. Roselyn, Genetic algorithm based reactive power dispatch for voltage stability improvement, Electrical Power and Energy Systems 32 (2010) 1151–1156.

6. C. Vournas, M. Karystianos, Load tap changers in emergency and preventive voltage stability control, IEEE Transactions on Power Systems, Vol. 19, No. 1, Feb. 2004, pp. 492-498.

7. Costas D. Vournas, On the role of LTCS in Emergency and Preventive Voltage Stability Control IEEE/PES Winter Meeting, New York, Jan. 2002, pp, 854-859.

8. T. V. Cutsem, An approach to corrective control of voltage in stability using simulation and sensitivity, IEEE Transactions on Power Systems, Vol. 10, No. 3, May 1995, pp. 616-622.

9. B. I. L. Lopes, A. C. Z. de Souza, On multiple tap blocking to avoid voltage collapse, Electric Power Systems Research 67 (2003) 225–231.

10. B. Milosevic, M. Begovic, Voltage-stability protection and control using a wide-area network of phasor measurements, IEEE Transactions on Power Systems, Vol. 18, No. 1, Feb. 2003, pp. 121-126.

11. http://www.ee.washington.edu/rese