RESEARCH ON LFB METHOD FOR RADIATING DISTRIBUTION NETWORK WITH TCSC DEVICE FOR VOLTAGE ADJUSTMENT

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Abstract

The paper analyzes the radial distribution power system with the series connection of FACTS devices, which is easily implemented using a formula from the power flow equation (PFE - power flow equation) with the voltage magnitude and power flow on the lines are treated as independent variables. When control variables such as the form of reactive power at nodes and lines are directly manipulated in the formulation, the application of FACTS device control operations in the power system is carried out quickly and directly. Using the ratio matrix at the nodes of a radial distribution system is primarily represented on the main diagonal to reduce computational procedures. All FACTS device models are unified under static stability conditions and can be easily integrated within the new framework through the process of "variable exchange". Using the IEEE standard system, the formulation of the formula is based on the trend on the line - Line Flow Based (LFB) by the author to provide easy implementation with multiple FACTS devices connected in the system and its efficiency.

Keywords: Distribution power flow analysis, flexible AC transmission system (FACTS), power system planning and modeling, voltage controls

1. Introduction

The load demand is constantly increasing, along with the daily and hourly development of science and technology. The demand for power quality must also meet the requirements of the load. Achieving power quality ensures the supply of electricity to customers while being capable of responding effectively to sudden fluctuations in the power system due to disturbances under static conditions, such as overloads caused by power imbalances on the grid during generation and consumption processes, leading to significant voltage drops, phase angle shifts, system instability, and the risk of unsafe system operation. FACTS devices were developed to meet that requirement flexibly and quickly.

Currently, in developed countries, especially those with relatively stable power systems, there is a demand for consistently stable output voltage quality to ensure the stable operation of highly sensitive loads. The integration of FACTS devices into the system for rapid voltage stabilization is a crucial task for the power grid.

Flexible Alternate Current Transmission Systems (FACTS) devices play a leading role in efficiently controlling power flow on transmission lines and improving the voltage profile at nodes in the power system. These new devices can reliably and effectively enhance the power transmission and distribution system. The control and flexibility in operation are very high. Typically, power flow is analyzed using the Newton-Raphson method and the fast Decoupled algorithm, which have been adjusted to include FACTS device models in the transmission system.

The main objectives of FACTS devices installed on distribution lines are to improve voltage regulation, standard power factor, and reduce power losses on the line. The distribution line has a high R/X ratio, affecting the convergence issue in the traditional power distribution and voltage stability calculation problems.

As before, to calculate the power distribution on the line, we use the traditional Newton-Raphson method. This calculation encounters a lot of difficulties in finding the Jacobian matrix. Another method used to calculate power distribution is the Line Flow Basic method, abbreviated as the LFB method for solving power distribution problems based on power flow on transmission lines.

For the distribution grid, we use the LFB method to calculate voltage stability. The paper that the author is researching is "**Research on LFB method for radiating distribution network with TCSC device for voltage adjustment**".

This is a method for calculating useful power distribution and is very convenient for current power distribution calculations.

With the LFB method: No need to form the Jacobian matrix, easily integrate FACTS devices such as TCSC, SVC, TCVR..., no need to calculate trigonometric functions, for the radial structure and conventional power distribution calculation (without considering FACTS devices and without DG), it is entirely possible to calculate the active and reactive power flow on feedes and voltage at nodes using the backward and forward substitution methods without needing to invert the matrix, and to calculate the reactance value.

The LFB method reduces the computational procedures in the power distribution problem with the FACTS device being TCSC.

Applying the LFB method on a real grid with the power distribution problem on a multi-source distribution grid is easily accomplished with many TCSC devices in the system and allows for the estimation of the effectiveness brought by FACTS devices.

2. General model of FACTS devices with line segment.

General model of FACTS devices with a common line segment as shown in Figure 1.

A transformer with phase angle parameters and tap position. The parameters r_l and x_l are the resistance and reactance of the feed l, i and j are the sending and receiving node numbers of the feed l; p_l and q_l are the active and reactive power flows of the feed at the final receiving end of the feed l.

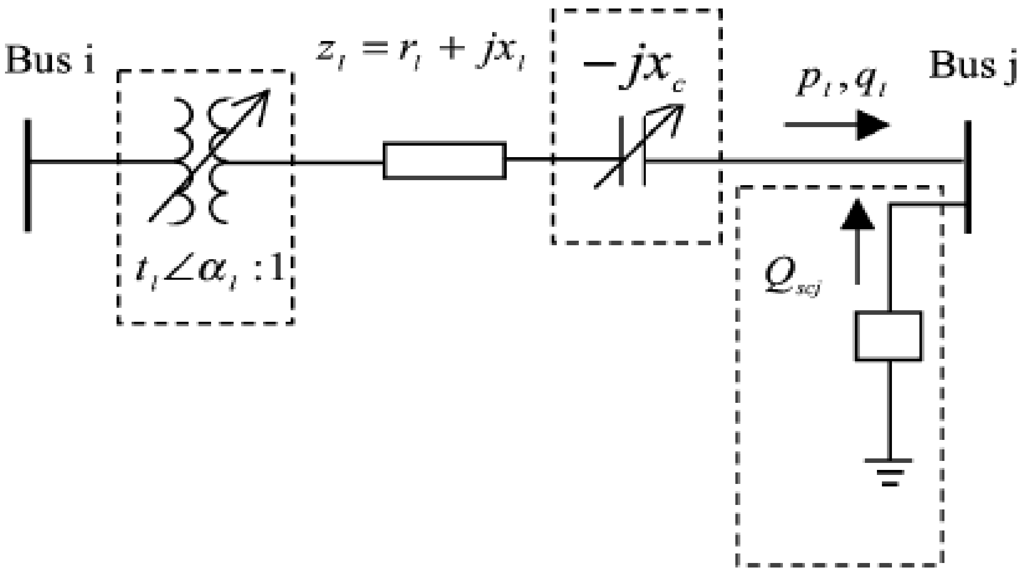

Figure 1. General model of FACTS devices with a common transmission line segment

3. Power distribution equation with LFB

a. General power balance equation

$$\mathrm{A.p - P_{GL} - A'.l = 0} \tag{1}$$

$$\mathrm{A.q - Q_{GL} - A'.m - H.V^2 = 0} \tag{2}$$

Matrix A with rows corresponding to all nodes except the system node.

A’: A node-to-node ratio matrix with all the “-1” values in A replaced by 0, created to easily accommodate line losses in the power balance equation when using the voltage drop vectors of the feedes l and m.

H: is the diagonal matrix, its diagonal elements are the sum of the forward and backward at each node.

P_{GL} and Q_{GL} : is the power vector input to the node defined by $P_{GLi} = P_{Gi} - P_{Li}$ and $Q_{GLi} = Q_{Gi} - Q_{Li}$

With: P_{Li}, P_{Gi} và Q_{Li}, Q_{Gi} are the active and reactive powers generated and consumed at node i.

l_1 and m_1 **:** loss of active power and reactive power of the line l.

p and q: power flow vector of active and reactive power on the line at the receiving end.

V^2 : unknown voltage vector minus system node.

V_i^2 : the square of the voltage magnitude at node i.

b. Feed voltage equation.

$$2Rp + 2Xq - (\Lambda A_{1+}^T + A_{1-}^T).V^2 = -k + \Lambda A_C^T V_{PV}^2 \tag{3}$$

Here:

A_c : is the node ratio matrix corresponding to the PV nodes.

V_{PV}^2 : is the squared voltage vector of the PV nodes and the system node.

Λ :is the diagonal matrix arranged equal to l the values of a feed conversion balance of the A_{1+} and A_{1-} step values achieved when A_1 is set accordingly, the negative and positive values in A_1 are 0.

R, X : is the diagonal matrix of resistance and reactance.

$$k_l = s_2^l(r_2^l + x_2^l)/V_j^2 .$$

c. LFB power flow equation

Equations (1), (2), and (3) are placed in the sample matrix as follows:

$$\begin{bmatrix} A & 0 & 0 \\ 0 & A_1 & 0 \\ 2R & 2X & -(\Lambda A_{1+}^T + A_{T-}^1) \end{bmatrix} \begin{bmatrix} p \\ q \\ V^2 \end{bmatrix} = \begin{bmatrix} P_{GL} \\ Q_{GL} \\ \Lambda A_C^T V_{pv}^2 \end{bmatrix} - \begin{bmatrix} A'l \\ A_1^{\cdot} - H_1 V^2 \\ k \end{bmatrix} \quad (4)$$

d. Establish the LFB formula with the FACTS device as TCSC.

$$2x_C q_l - \frac{V_i^2}{t_l^2} = -\frac{s_l^2 z_l^2}{V_j^2} - V_j^2 - 2r_l p_l - 2x_l p_l - 2x_l q_l \quad (5)$$

This is the LFB power flow equation. The total number of unknowns is:

$$N = 2(n-1) + n - n_{pv} - 1 = 3(n-1) - n_{pv}$$

Equation (4) is written in the following characteristic form:

$$A_{pq} V^2 x = y_1 + y_2 \quad (6)$$

The coefficient matrix $A_{pq}V^2$ is an invariant matrix that only needs to be a factor immediately during the problem-solving process.

The coefficient matrix is incorrect when it is a star network but is a tree structure with all feedes connected, and the rows corresponding to the feedes of the tree in the network diagram are considered independent.

x is the variable of the vector of active power and reactive power flow p, q, and the square of the node voltage magnitude V^2;

y_1 is the constant input power vector and the PV voltage node;

y_2 is a vector variable of feed losses, feed charging, and feed balancing. The iterative power flow analysis begins with the vector y_2 set to zero. Using the vector problem in one iteration, the right-hand side of (6) is immediately executed by the calculation vector y_2 and supplemented to the vector y_1.

4. Survey the problem according to LFB with TCSC attached to adjust the voltage of a multi source network.

a. Algorithm diagram

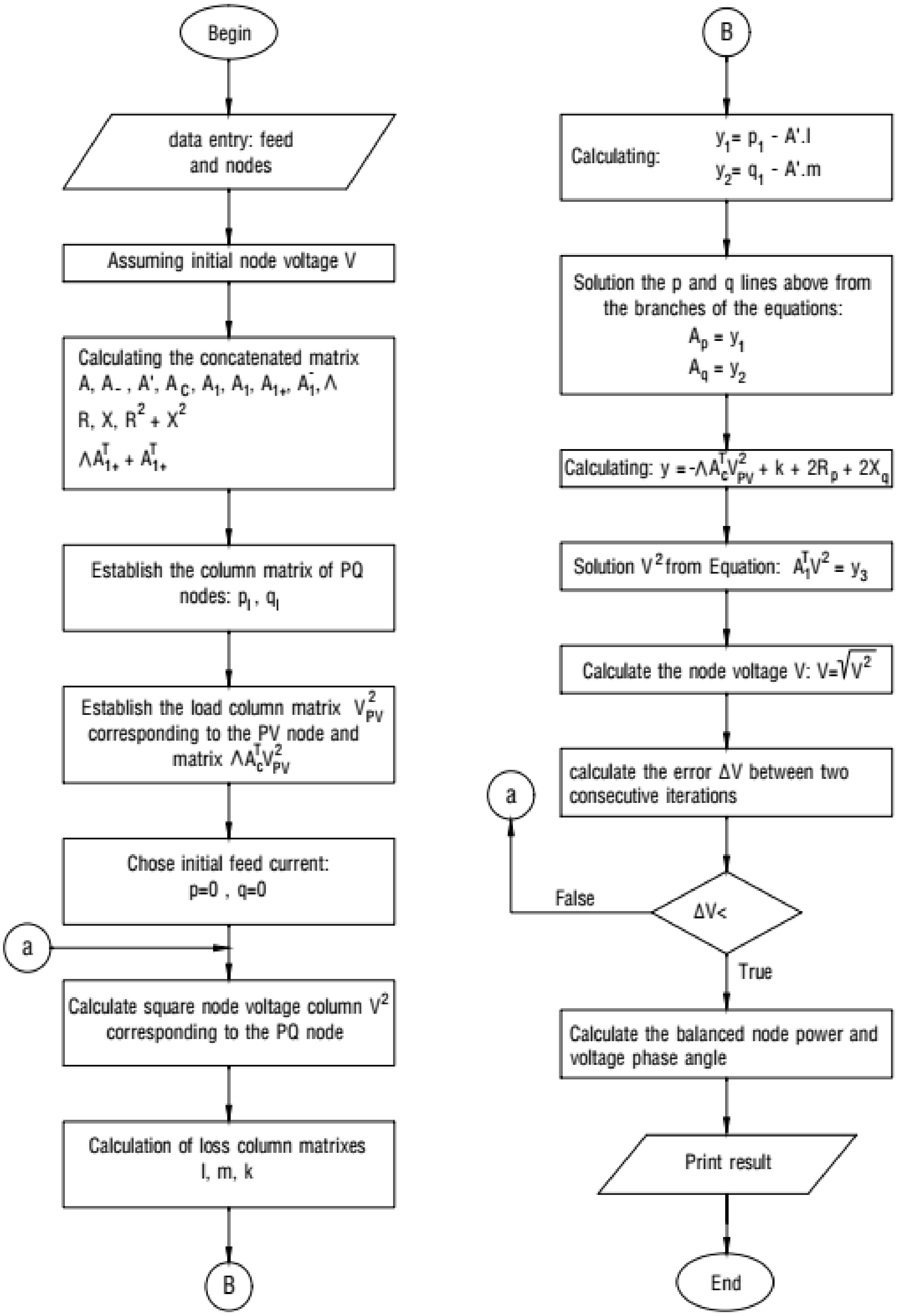

Figure 2. Flowchart of the algorithm for solving the PBCS LFB problem

b. Survey the problem.

```
Initial data
Quantity node:     16
Quantity feed:     15
Balance node: 1
Basic power: 10 MVA
```

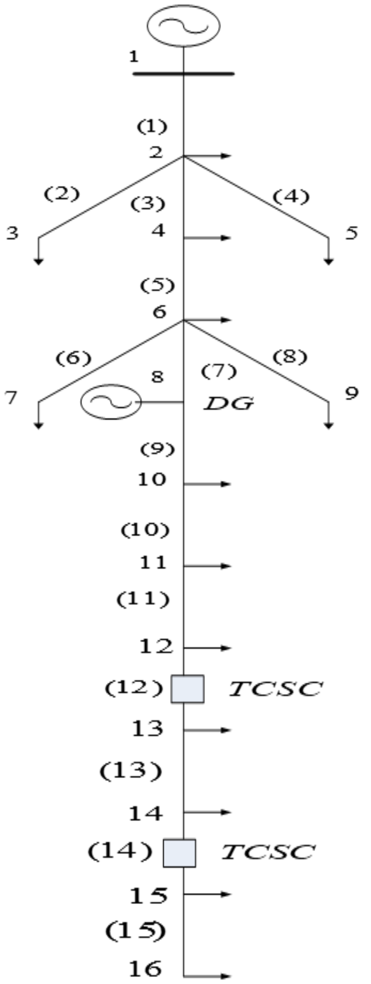

Figure 3. Tree diagram of a 16-feed 15-node star network

Feed position:

```
Feed 1 : starting point 1 end point 2
Feed 2 : starting point 2 end point 3
Feed 3 : starting point 2 end point 4
Feed 4 : starting point 2 end point 5
Feed 5 : starting point 4 end point 6
```

```
                    Feed  6  :  starting point   6    end point
7
                    Feed  7  :  starting point   6    end point
8
                    Feed  8  :  starting point   6    end point
9
                    Feed  9  :  starting point   8    end point
10
                    Feed  10 :  starting point   10   end point
11
                    Feed  11 :  starting point   11   end point
12
                    Feed  12 :  starting point   12   end point
13
                    Feed  13 :  starting point   13   end point
14
                    Feed  14 :  starting point   14   end point
15
                    Feed  15 :  starting point   15   end point
16
```

Feed impedance:

```
                Feed impedance (relative units) :
```

Feed	Rn	Xn
1	0.005372	0.014460
2	0.005372	0.014460
3	0.005372	0.014460
4	0.005372	0.014460
5	0.005372	0.014460
6	0.005372	0.014460
7	0.005372	0.014460
8	0.005372	0.014460
9	0.005372	0.014460
10	0.005372	0.014460
11	0.005372	0.014460
12	0.005372	0.014460
13	0.005372	0.014460
14	0.005372	0.014460
15	0.005372	0.014460

```
Type of node 1 : node PV
Type of node 0 : node PQ
```

Matrix A:

```
        Number of rows equals number of node - 1
        Number of columns equals number of feed
```

-1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	-1	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-1	1	1	1	0	0	0	0	0	0	0
0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	-1	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	-1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	-1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1

c. Calculation results.

When there is no DG, the node voltage value:

Node	V(pu)	delta(degree)
1	1.00000	0.00000
2	0.96075	-1.33757
3	0.95736	-1.46753
4	0.93208	-2.37210
5	0.95736	-1.46753
6	0.90717	-3.32634
7	0.90358	-3.47216
8	0.89321	-3.87953
9	0.90358	-3.47216
10	0.88294	-4.29634
11	0.87637	-4.56667
12	0.87167	-4.76226
13	0.86791	-4.92026
14	0.86509	-5.03966
15	0.86321	-5.11969
16	0.86227	-5.15984

When there is DG, the node voltage value:

Node	Type	V(pu)	V(kV)	delta(degree)
1	1	1.00000	22.000	0.0000
2	0	0.98306	21.627	-1.1464
3	0	0.97975	21.554	-1.2705
4	0	0.97634	21.480	-1.9469
5	0	0.97975	21.554	-1.2705
6	0	0.97311	21.409	-2.6298
7	0	0.96977	21.335	-2.7564
8	1	0.98000	21.560	-2.9341
9	0	0.96977	21.335	-2.7564
10	0	0.97068	21.355	-3.2796
11	0	0.96474	21.224	-3.5030
12	0	0.96048	21.131	-3.6642
13	0	0.95707	21.056	-3.7943
14	0	0.95452	20.999	-3.8924
15	0	0.95281	20.962	-3.9581
16	0	0.95196	20.943	-3.9911

When there is DG and 2TCSC on feedes 12 and 14, the node voltage value:

Node	Type	V(pu)	V(kV)	delta(degree)
1	1	1.00000	22.000	0.0000
2	0	0.98306	21.627	-1.1462
3	0	0.97975	21.554	-1.2703
4	0	0.97634	21.480	-1.9466
5	0	0.97975	21.554	-1.2703
6	0	0.97311	21.409	-2.6293
7	0	0.96977	21.335	-2.7559
8	1	0.98000	21.560	-2.9334
9	0	0.96977	21.335	-2.7559
10	0	0.97088	21.359	-3.2830
11	0	0.96513	21.233	-3.5104
12	0	0.96106	21.143	-3.6756
13	0	0.98000	21.560	-1.9745
14	0	0.97755	21.506	-2.0690
15	0	0.99000	21.780	-1.0174
16	0	0.98918	21.762	-1.0479

5. Survey results of the LFB problem with TCSC attached to adjust the voltage of a multi-source network.

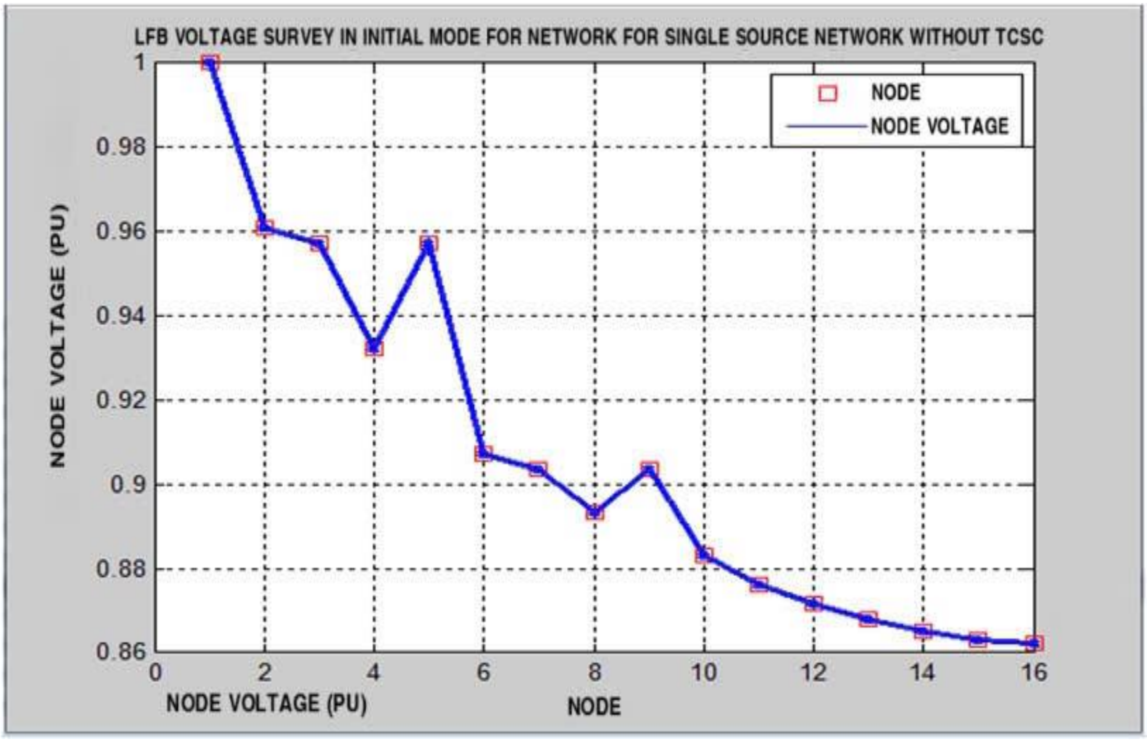

Figure 4. Simulation results of the network with one source without TCSC

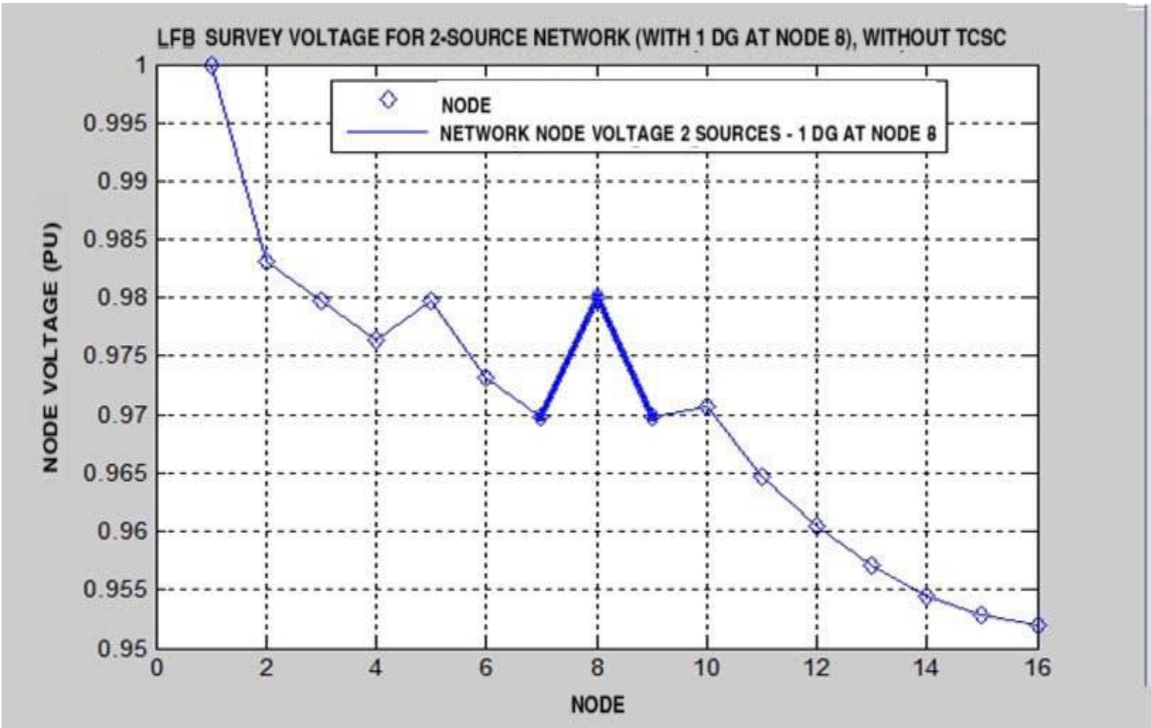

Figure 5. Simulation results of a 2-source network (with 1 DG) without TCSC

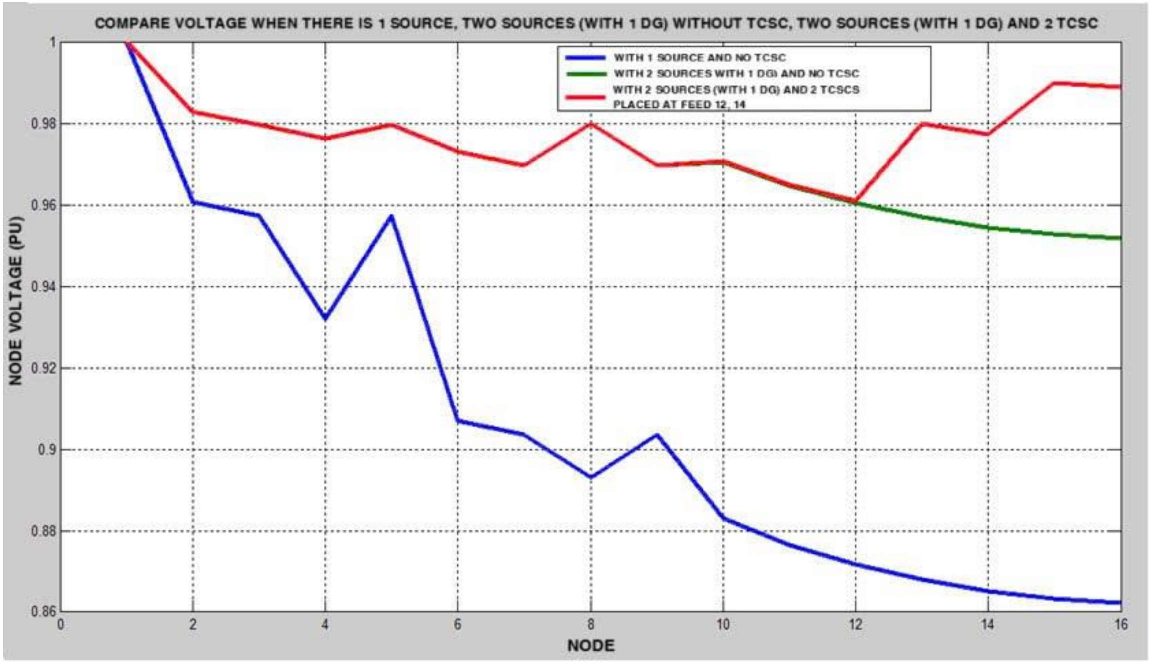

Figure 6. Simulation results of the network with 2 sources (with 1 DG), 2 TCSC feedes 12, 14

From the graph in Figure 4, we observe that the voltage at node number 8 is very low (0.89321pu). For the distribution grid, the allowable operating voltage is within the permissible limits (1 ± 5%). We choose this location to install the DG generator.

From the graph in Figure 5, place the distributed generator DG at node number 8. Introducing the generator into the power grid acts as a PV node, functioning as a generating node. At node number 8, the voltage increases significantly. After placing the DG at node 8, the voltage there rises to 0.98 (pu) instead of 0.89321 (pu) before the DG was added.

From the graph in Figure 6, after placing the TCSC into the grid, at nodes 12 and 14, the voltage values at those nodes and some neighboring nodes such as 13, 15, and 16 increased significantly. Thus, the introduction of the TCSC device into the surveyed power grid significantly improved the voltage levels.

In summary, the investigation of the LFB method on a radial distribution network with the installation of TCSC devices for voltage regulation is a case study that yields correct and accurate results for each scenario in the process of solving the power distribution problem. The effectiveness is achieved by placing TCSC devices at nodes where voltage needs to be increased to ensure the output voltage of the feedes on the main distribution line.

6. Conclusion.

Researching the LFB method for a radial distribution network with multiple sources and TCSC devices installed on the grid to adjust voltage appropriately in a radial power system is a novel approach that has been validated for accuracy and suitability using traditional calculation methods, specifically the Newton-Raphson method.

The LFB formula is established using the magnitude of node voltage and power flow on FACTS devices under system operating conditions. These control variables are implemented with the transmission line as independent variables and are directly linked to the device variables, which are directly implemented as the reactive power diagram of the node and the transmission line.

The LFB formula has been thoroughly investigated and is completely accurate with the power distribution grid, and the results of the problem have been proven to converge.

Surveying TCSC using the LFB method aims to:

Adjusting the voltage at the terminal node on the feed with TCSC and evaluating the effectiveness of the LFB method in integrating TCSC. The results are verified using conventional power distribution methods such as Newton Raphson, Gauss Seidel, and Fast Decouple.

Adjust the voltage so that the voltage at the end of the line has a voltage drop less than the allowable limit.

The placement of the TCSC is such that it has the smallest power while still ensuring the allowable voltage drop to the end of the line.

Suitable for a radial electrical network.

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