Load Flow Analysis For

Meshed Network Using Backward/Forward Sweep Method

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Abstract— **Involves the development of a Matlab program which analyzes load flow in distribution system in mesh network with a defined number of nodes, real and reactive load power consumption at the nodes through the forward-backward load flow algorithm for IEEE 33 bus network.**

1. Introduction

Load flow analysis is the study of the flow of electrical power in a system of electrical buses. It is essential as it helps to plan the construction and expansion of the system. There are various numerical techniques to perform load flow analysis such as Gauss-Seidel, Newton-Raphson, fast decoupled method, Backward/Forward sweep, etc. Here we go for Backward/Forward sweep method for its simplicity and low computing cost amongst the others. IEEE has defined specific systems with fixed no of buses like 33, 69, etc. These test systems can be used to test the convergences of various load flow analysis algorithms. We make use of IEEE standard 33 bus system, which is the radial connected bus system to check the convergence of the Backward/Forward sweep method for the original system as well as for a modified weakly meshed network system.

A. Radial System

It is the most simple and commonly constructed network among the distributed system. Here all the buses are connected in series, which may be branched or unbranched. The variation in voltage profile for this type of system is a linear decrease across each of the buses, due to this voltage profile across the nodes away from the central source node has a drastic drop in their magnitude as compared to the source node voltage.

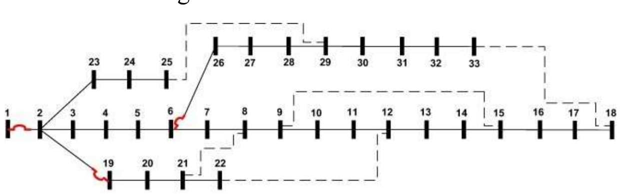


Fig 1. IEEE 33 bus system - Radial Network

B. Meshed Network System

The problem faced by the radial system is the poor voltage profile faced by the nodes away from the source node the system. To improve the voltage profiles, we make use of interconnection between various nodes of the bus system. These interconnections allow the fraction of current across the bus with poor voltage profile through it, thus decreasing the effective drop in voltage across the impedance line increasing the voltage of the buses enclosed by the interconnections.

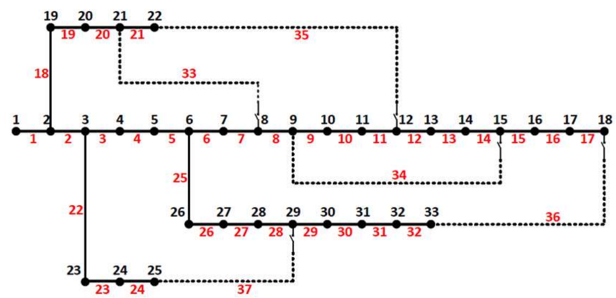


Fig 2. IEEE 33 bus system - Meshed Network

I. Methodology

A. Backward/Forward sweep method

The first step of this method is to initialize all the bus voltages to 1 angle 0, i.e., flat start and the load current of each bus is calculated through the bus data provided.

$$\left(\frac{P\,i+jQi}{V\,i}\right)^*$$

This is followed by the backward sweep, where all branch currents are sequentially calculated from all end nodes to the start node using KCL.

$$I_{ij} = I_j + \sum_k I_{jk}$$

where, I_{ij} is the current flowing the branch from i^{th} bus to j^{th} bus, and the second term is the sum of all branch currents flowing out of the j^{th} bus. Once, the branch currents for a given iteration have been calculated, the backward sweep ends. The next step is the forward sweep which sequentially calculates the bus voltages from the start bus to the end bus using KVL.

$$V_i = V_{i-1} - I_{i-1i} \cdot Z_{i-1i}$$

B. Weakly Meshed Network

The method is modified when the system is changed from a radial network to a weakly meshed network. Both backward and forward sweep steps are carried out the same way ignoring the newly added interconnections. After the updated voltage profiles are obtained from the forward sweep, these are used to update the value of interconnection branch current and the backward sweep equation has an extra term to take these connections into account.

$$I_{ij} = I_j + \sum_k I_{jk} - \sum_{l,\, l \neq i} I_{lj}$$

The extra term represents all the branch currents flowing into the j[th] bus.

III. Matlab code

A. main.m

```
Vk = ones(33,1);
Vkprev = zeros(33,1);
Ik = zeros(33,1);
reg_branches = 32;
eps = 0.01;
nodes = (1:length(Vk));
end_nodes = find(~ismember(nodes,I_branch(:,1)));
is_end_node = ismember(nodes, end_nodes);
n_of_endnodes = length(end_nodes);
n_of_branches = length(I_branch);
n_iter = 10;
e = zeros(n_iter,1);
i=1;
for i = (1:n_iter),
    %Backward Sweep
    Ik = conj(Sl./Vk);
    I_branch(1:reg_branches,3) = 0;
    for end_node = (1:n_of_endnodes),
        n = end_nodes(end_node);
        while n~=1,
            out_idx = find(I_branch(1:reg_branches,2)==n);
            in_idx = find(I_branch(1:reg_branches,1)==n);
            interco_idx = find(I_branch(reg_branches+1:n_of_branches,2)==n);
            I_branch(out_idx,3) = I_branch(out_idx,3) + Ik(n) + sum(I_branch(in_idx,3)) - sum(I_branch(interco_idx,3));
            Ik(n)=0;
            n = I_branch(out_idx,1);
        end
    end

    %Forward Sweep
    Vkprev = Vk;
    Vk = forwardSweep(I_branch, Z_branch, Vk, is_end_node, 1);
    e(i) = max(abs(Vk - Vkprev));

    %if(e(i) < eps)
        %break;
    %end

    %Interconnect current
    for i =(reg_branches+1:n_of_branches),
        in_bus = I_branch(i,1);
        out_bus = I_branch(i,2);
        I_branch(i,3) = (Vk(in_bus)-Vk(out_bus))/Z_branch(i,3);
    end
end
disp(abs(Vk));
x = (1:n_iter);
plot(x, e);
```

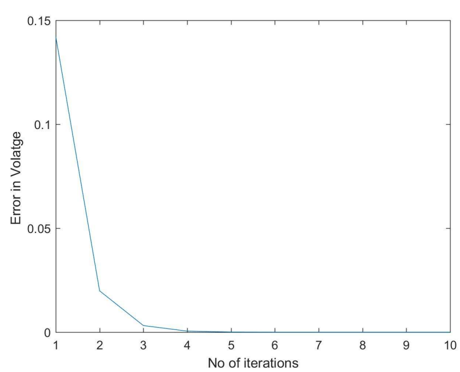
B. forwardSweep.m

```
function [ Vk ] = forwardSweep ( I_branch, Z_branch, Vk, is_end_node, node )
%   The input node is checked to see if it is an end node or not. If it
%   is not an end node, the function proceeds to find the number of
%   branches going out from the node. For each branch going out of the node
%   the funciton is recursively called until the end node of that branch is
%   reached
if(is_end_node(node) ~= 1),
    in_idx = find(I_branch(:,1)==node);
    for i = (1:length(in_idx)),
        out_bus = I_branch(in_idx(i), 2);
        Vk(out_bus) = Vk(node) - Z_branch(in_idx(i), 3)*I_branch(in_idx(i), 3);
        Vk = forwardSweep (I_branch, Z_branch, Vk, is_end_node, out_bus);
    end
end
end
```

The bus data is stored in the file called data . m

IV. Result

1. Convergence



This is the convergence plot for the backward /forward sweep algorithm.

2. Radial System (IEEE 33 Standard Bus)

Bus No.	Voltage Magnitude (p.u.)
1	1.0000
2	0.9860
3	0.9426
4	0.9242
5	0.9094
6	0.8818
7	0.8782
8	0.8642
9	0.8577
10	0.8517
11	0.8508
12	0.8492
13	0.8429
14	0.8406
15	0.8391
16	0.8377
17	0.8356
18	0.8349
19	0.9855
20	0.9821
21	0.9814
22	0.9808
23	0.9390
24	0.9324
25	0.9291
26	0.8798
27	0.8772
28	0.8655
29	0.8571
30	0.8534
31	0.8491
32	0.8482
33	0.8479

The voltage profiles were found for a basic 33 bus radial system and will be used as a reference to compare the voltage profiles with that obtained for the weakly meshed system.

3. Weakly Meshed System (IEEE 33 Standard Bus)

For the weakly meshed system, the following interconnections are taken:

8→21
9 →15
12→22
18→33
25→29

Bus No.	Voltage Magnitude (p.u.)
1	1.0000
2	0.9984
3	0.9930
4	0.9893
5	0.9857
6	0.9768
7	0.9768
8	0.9768
9	0.9768
10	0.9768
11	0.9768
12	0.9768
13	0.9768
14	0.9768
15	0.9768
16	0.9768
17	0.9768
18	0.9768
19	0.9979
20	0.9945
21	0.9939
22	0.9933
23	0.9930
24	0.9930
25	0.9930
26	0.9751
27	0.9728
28	0.9627
29	0.9930
30	0.9899
31	0.9862
32	0.9854
33	0.9852

On comparing the results, the average voltage profile across the system increases with interconnections.

4. Comparison

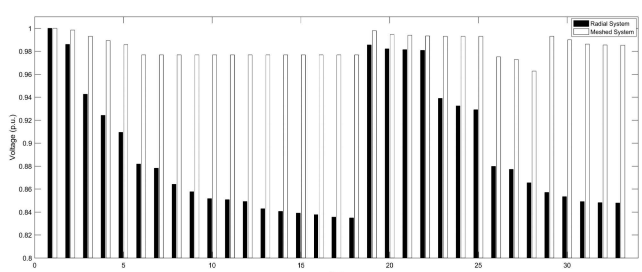


Fig 3. Comparison of voltage profiles of radial and meshed network systems

As we can see from the comparison plot, the voltage profile of the system improves when the buses are enclosed in the interconnections. Thus providing the meshed network a significant practical applicability when the compared to the latter system, thus resulting in the improvement in connectivity of various range of loads to the system.

V. Conclusion

It is found that as we move away from the source node, the voltage profile decreases. This can be mitigated by having multiple source nodes supplying power to a single distribution system. The voltage profiles in a standard radial distribution system can be improved by adding interconnections between buses. Backward/Forward sweep method converges fast due to the lower computing cost associated with the method.

VI. Future work

The future stage of the project is to implement a algorithm to calculate the optimal no of interconnections across the nodes such that the voltage profile of the system results in a maxima compared to other configuration and also improve the convergence rate for the extended IEEE 69 Bus System.

VII. References

[1] J. A. Michline Rupa, S. Ganesh, “Power Flow Analysis for Radial Distribution System Using Backward/Forward Sweep Method,” World Academy of Science, Engineering and Technology International Journal of Electrical and Computer Engineering Vol:8, No:10, 2014

[2] Durgit Kumar, Shwetank Agrawal, “Load Flow Solution For Meshed Distribution Networks”, 2013.x

VIII. Appendix

1. Appendix 1-Branch Data For IEEE-33 Bus System

In Bus No.	Out Bus No.	Impedance $(R + Xj)\,\Omega$
1	2	0.0922 + 0.0477j
2	3	0.493 + 0.2511j
3	4	0.366 + 0.1864j
4	5	0.3811 + 0.194j
5	6	0.819 + 0.707j
6	7	0.1872 + 0.6188j
7	8	1.7114 + 1.2351j
8	9	1.03 + 0.74j
9	10	1.04 + 0.74j
10	11	0.1966 + 0.065j
11	12	0.3744 + 0.1238j
12	13	1.468 + 1.155j
13	14	0.5416 + 0.7129j
14	15	0.59 1+ 0.526j
15	16	0.7463 + 0.545j
16	17	1.289 + 1.721j
17	18	0.732 + 0.574j
2	19	0.164 + 0.1565j
19	20	1.5042 + 1.3554j
20	21	0.409 5+ 0.4784j
21	22	0.7089 + 0.9373j
3	23	0.4512 + 0.3083j
23	24	0.898 + 0.7091j
24	25	0.896 + 0.7011j
6	26	0.203 + 0.1034j
26	27	0.2842 + 0.1447j
27	28	1.059 + 0.9337j
28	29	0.8042 + 0.7006j
29	30	0.5075 + 0.2585j
30	31	0.9744 + 0.963j
31	32	0.3105 + 0.3619j
32	33	0.341 + 0.5302j

2. *Appendix 2 - Branch Data For Interconnections*

In Bus No.	Out Bus No.	Impedance (R + jX) Ω
8	21	0.4 + 0.4j
9	15	0.4 + 0.4j
12	22	0.4 + 0.4j
18	33	0.4 + 0.4j
25	29	0.4 + 0.4j