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A Novel Direct Approach to Load Flow for Distributed System using Voltage Stability Index

[1]Kanwalpal Singh, [2]Prof. Rajni Bala
[1]Student, [2]Professor
[1]BBSBEC, Fatehgarh Sahib,Punjab
[2]BBSBEC, Fatehgarh Sahib,Punjab

***Abstract* - Load flow has always been a critical problem and has been approached by several researchers. The techniques like Newton Raphson and Gauss Siedel works well but has severe computational disadvantages.The purpose of this paper is to analyse the voltage stability of electric power distribution system. A new method is established for computing voltage stability index (VSI) for each nodes of any distribution network. The most sensitive node is that node which having minimum value of voltage stability index. This paper proposes a novel direct method to load flow for distribution systems. The system has been simulated for constant power load considering losses. The methodology has been implemented on MATLAB R2013b and voltages of each bus are found out and real and reactive losses are calculated. Also the most sensitive node is found out. The results shows an improvement over traditional methods**

***Keywords* - Voltage Stability Index, Distribution System, Load flow**

I. INTRODUCTION

Modern power grids are extremely difficult and widespread. Surges in power lines can cause massive network failures and permanent damage to multimillion dollar equipment in power generation plants. After electricity is generated at power plants it has to get to the customers that use the electricity. The transmission and distribution system delivers electricity from the generating site (electric power plant) to residential, commercial, and industrial facilities. The electricity first goes to a transformer at the power plant that boosts the voltage up to 400 kVA for transmission through extra-high voltage (EHV) transmission lines. When electricity travels long distances, it is improved to have it at higher voltages since the electricity can be transferred more efficiently at high voltages. High voltage transmission lines carry electricity long distances to a substation. At transmission substations a decrease in voltage occurs for distribution to other points in the system through high voltage (HV) transmission lines. Further voltage reductions for commercial and residential customers take place at distribution substations, which connect to the primary distribution network. Transformers are a crucial link in the electric power distribution system. Utility transformers are high-voltage distribution transformers typically used by utilities to step down the voltage of electricity going into their customers' buildings. Distribution transformers are one of the most widely used elements in the electric distribution system. They convert electricity from the high voltage levels in utility transmission systems to voltages that can safely be used in businesses and homes. Distribution transformers are either mounted on an overhead pole or on a concrete pad. Most commercial and industrial buildings require several low-voltage transformers to decrease the voltage of electricity received from the utility to the levels used to power lights, computers, and other electric-operated equipment.

Distribution System The part of power system which distributes electric power for local use is known as distribution system. In general, the distribution system is the electrical system between the substation fed by the transmission system and the consumers' meters. It usually consists of feeders, distributors and the service mains.

(i)Feeders: A feeder is a conductor, which connects the sub-station (or localized generating station) to the area where power is to be distributed. Normally, no tapings are taken from the feeder so that the current in it remains the same throughout.

(ii) Distributor: A distributor is a conductor from which tapings are taken for supply to the consumers. The current through a distributor is not constant because tapping are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ± 10% of rated value at the consumer's terminal.

(iii) Service mains: A service mains is usually a small cable which connects the distributor to the consumer's terminals.

A.C. Distribution Nowadays electrical energy is generated, transmitted and distributed in the form of alternating current. One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer. Transformer has made it possible to transmit a.c. power at high voltage and utilize it at a safe 4 potential. High transmission and distribution voltages have greatly decrease the current in the conductors and the resulting line losses. There is no definite line between transmission and distribution according to voltage or bulk capacity. However, the down sub-station is fed by the transmission system and the consumers' meters. The a.c. distribution system is classified into (i) primary distribution system and (ii) secondary distribution system.

The problem of load flow in power system forms an example of a classic engineering problem in power system. In most of the cases of circuit analyses, the network components are limited to known value of impedances with current and voltage source. But the load flow problem is different in the sense that instead of impedances, the known quantities are active and reactive powers at most network buses, because behavior of most of the load in a lot of cases are as constant power loads, assuming that voltages applied on them remains within acceptable ranges.

The set of unknowns producing power balance at all of the specified buses in the system is solved by the load flow algorithm. The power balance equation is given by equation1:

$$P_i^{given} + jQ_i^{given} = P_i^{comp} + jQ_i^{comp} \quad (1)$$

where

$$P_i^{comp} + jQ_i^{comp} = V_i I_i^* \ . \quad (2)$$

This paper proposes a novel algorithm of direct approach for distribution load flow problem considering voltage stability index. The method minimizes the computation effort compared to traditional methods. Section II describes the literature survey taken from various papers which have discussed relevant works. Section III discusses our problem statement and Section IV provides a description of our proposed methodology and results are put together in section V. Finally the paper concludes with a brief discussion the overall results.

II. LITERATURE REVIEW

Brownell *et al.* [7] provided the recordings of increased load demand of a system and showed its voltage collapse. They also proposed urgent compensation of reactive power.

Jasmon and Lee *et al.* [8] proposed a voltage stability analysis of radial distribution networks. They reduced the whole network by its single line diagram that is valid only at the derived operating point. They had put voltages of all nodes equal to 1.0 pu to simplify the derivation of voltage stability index. This method is unable to handle changing load pattern.

Rahman *et al.* [10] proposed a method to study the voltage collapse using Thevenin's theorem. They suggested a voltage stability index.

Gubina *et al.* [11] proposed a method to study voltage stability analysis of radial distribution networks reducing the system model to its single line equivalent.

Chakravorty *et al*. [12] proposed a voltage stability index to identify the most sensitive node of the network. They handled the composite load using power convergence and used the load−flow technique

Ranjan *et al.* [13] suggested a new voltage stability index to identify the most sensitive node of the network. They assumed the equality of magnitude of voltage for sending−end node and receiving−end node of each branch while deriving voltage stability index. They have shown that critical loading for constant impedance load is maximum
.

Haiyan Chen, Jinfu Chen, Xianghong Duan, Dongyuan Shi *et al*. [14] discussed the familiar interfaces between DGs and distribution networks. The operation modes and control characteristics of typical DGs, including asynchronous generators, synchronous generators with constant values of excitation voltage, and fuel cells, are analyzed. Based on the models of DGs proposed in power flow calculations, a new method for constructing a sensitivity matrix is presented, which is available to calculate the power flow of distribution networks with multiple types of DGs. Using this method presented in this paper, the impacts of DGs on the system voltage stability are studied... Some important conclusions are obtained. A 90-bus system is analyzed to give an illustration of the feasibility of the proposed method.

Peter Dondi, Deia Bayoumi, Christoph Haederli, Danny Julian,Macro Suter *et al* [15] Suggested that the position of distributed generation (DG, as these small units are called in comparison with central power plants) with respect to the installation and interconnection of such units with the classical grid infrastructure.

Tareq Aziz, Tapan Kumar Saha, Mithulananthan Nadarajah *et al* [16] proposed the identification of the weakest bus in a distribution system with load uncertainties using reactive power margin. In this study, reactive power margin has been used as a stability index which appears as a reliable index to determine critical or weak node while considering the influence of load uncertainties. Effectiveness of reactive power margin index has been proved using a modified 16 bus primary distribution system

III. PROBLEM FORMULATION

The problem of load flow in power system forms an example of a classic engineering problem in power system. In most of the cases of circuit analyses, the network components are limited to known value of impedances with current and voltage source. But the load flow problem is different in the sense that instead of impedances, the known quantities are active and reactive powers at most network buses, because behavior of most of the load in a lot of cases are as constant power loads, assuming that voltages applied on them remains within acceptable ranges. From the point of view of load flow studies, following four parameters at each bus are of utmost importance - the magnitude of voltage 'V', the voltage angle 'δ', active power 'P', and reactive power 'Q'.

Out of these four two are usually specified while for the other two calculations needs to be performed. Since, active and reactive power are given in most of the cases, while V and δ are to be calculated but it varies as the bus type varies. It is obvious that it is not possible to specify P and Q at all busses because that would lead us to the implication of having a prior knowledge of the losses which is not the case. Hence, the load flow problem must include one "swing bus" or "slack bus". An important characteristic of the slack bus is that the power of slack bus can assume any value so as to compensate for the system losses. Usually the swing bus is located centrally and is attached with a large generator with specific voltage magnitude and phase angle.

The thesis work endeavors to derive a new expression of voltage stability index (VSI) and its applications in planning of power distribution system. The objectives are divided into the following:

- To derive a new expression of VSI to e computed for all nodes of the distribution networks.
- To indentify the most sensitive nodes of the distribution networks.
- To compute the critical values of total real power load (TPL) and total reactive power load (TQL) of the system.

VI. METHODOLOGY

This paper proposes a novel algorithm of direct approach for distribution load flow problem considering voltage stability index. The method minimizes the computation effort compared to traditional methods. A balanced load that can be represented either as constant power, constant current, constant impedance or as an exponential load is considered here. The general expression of load is shown below.

$$P = Pn\,[a0 + a1V(m2) + a2V2(m2) + a3Ve1(m2)] \quad (1)$$

$$Q = Qn[b0 + b1V(m2) + b2V2(m2) + b3Ve1(m2)] \quad (2)$$

where, Pn and Qn are nominal real and reactive power respectively and V(m2) is the voltage at node m2.
For all the loads, Equations are modeled as

$$a0 + a1 + a2 + a3 = 1.0 \quad (3)$$

$$b0 + b1 + b2 + b3 = 1.0 \quad (4)$$

For constant power (CP) load a0 = b0= 1 and ai = bi = 0 for i = 1, 2, 3.
In this paper we have only taken Constant power load and applied our proposed method for 66 bus system and 33 bus system using the formula of voltage stability index.

Voltage stability is a property of power distribution system that enables it to stay in a state of equilibrium voltage under normal operating condition and the system also returns to an acceptable state of equilibrium voltage after a disturbance. Voltage stability is concerned with the ability of power system to maintain the steady acceptable voltages at all system buses under normal conditions as well as when the system is being subjected to a disturbance. If voltages after a disturbance are close to voltages at normal operating condition then the system is said to be stable. A power system becomes unstable when voltage uncontrollably decreases due to outage of equipment, increment of load, decrement of production. There are two types of voltage stability based on the time frame of simulation: static voltage stability and dynamic voltage stability. Static analysis involves only the solution of algebraic equations and hence is computationally less extensive than dynamic analysis. Static voltage stability is ideal for the bulk of studies in which voltage stability limit for many cases must be determined.

Voltage stability margin is the measure of the security level of VSM is high then bus is more secured and vice versa. Voltage Stability Margin of a power system is a measure to estimate the available power transfer capacity, net power transfer capacity or total power transfer capacity. Voltage stability margin (VSM) is widely accepted and easily understood index of voltage collapse. This is a difference or a ratio between the operation and voltage collapse points according to a key parameter (loading, line flow, etc).So, voltage stability margin can be calculated as follows:

$$VSM = \frac{V_{w(base)} - V_{w(critical)}}{V_{W(Critical)}} \qquad (5)$$

$V_{w(base)}$ = bus voltage of the weakest bus of the system at normal operating condition.

$V_{V_{w(critical)}}$ = bus voltage of the weakest bus of the system at voltage collapse point.

VSI(i)=V(i)^4-4*abs(V(1)^2)*(K*bdata(i,2)*ldata(i,4))-4*abs(V(1)^2)*(K*bdata(i,3)*ldata(i,5))-4*K*(bdata(i,2)*ldata(i,5)-bdata(i,3)*ldata(i,4))^2 (6)

Where VSI(i) represents the voltage stability index at bus 'i',

bdata(i,2) represents the real power at bus 'i'

bdata(i,3) represents the reactive power at bus 'i'

ldata(i,4) represents the real resistance of line 'i'

ldata(i,2) represents the reactance of line 'i'

V.RESULTS

The methodology has been implemented for 33 bus system and 69 bus system.

Table 1: Voltage Magnitude And Voltage Stability Index For 33 Bus System

Node no.	Voltage magnitude for 33 bus system	Node no.	Voltage Stability index for 33 bus system
1	1	1	1
2	0.984636275756693	2	0.990941713955735
3	0.982471213938966	3	0.973490102902086
4	0.981303193654027	4	0.928205740120358
5	0.979667039712484	5	0.926442090270828
6	0.979510213196510	6	0.918630507243517
7	0.979256065580960	7	0.901178726402977
8	0.972887830274846	8	0.868508304488720
9	0.972000794201463	9	0.857756863264221
10	0.968434560678081	10	0.848531218120891
11	0.960787118430649	11	0.848441699384748
12	0.957616898633417	12	0.842563931755053
13	0.950485929139142	13	0.838447892450760
14	0.947165976592173	14	0.830490227190920
15	0.924012208657415	15	0.820657231082734
16	0.921165146965632	16	0.773597432514810
17	0.916895832210708	17	0.751685466941381
18	0.943977242259890	18	0.712055216761806
19	0.977479379769253	19	0.982784438267097
20	0.977073714678197	20	0.969605003262417
21	0.972732744225833	21	0.961425681850119
22	0.970354153709969	22	0.934338120509556
23	0.968015009611324	23	0.918454157485906
24	0.967747908942687	24	0.911520090071734
25	0.965528165558808	25	0.905450893092698
26	0.958311708899064	26	0.856050799289808

27	0.956927752807741	27	0.844146211366210
28	0.956369818770940	28	0.844018161524087
29	0.946320589296808	29	0.835048012676713
30	0.945808743005254	30	0.818846152990652
31	0.938828743922108	31	0.799612185722523
32	0.926355280143746	32	0.793534288185042
33	0.921533267828406	33	0.777388886903518

Table 2: Voltage Magnitude and Voltage Stability Index for 69 Bus Systems

Node no.	Voltage magnitude for 69 bus system	Node no.	Voltage magnitude for 69 bus system	Node no.	Voltage Stability index for 69 bus system	Node no.	Voltage Stability index for 69 bus system
1	1	36	0.957849933559336	1	1	35	0.868141208219666
2	0.998761029949119	37	0.953862278750825	2	0.993696474032735	36	0.865033822911080
3	0.997706067802872	38	0.951210668126195	3	0.990871770251452	37	0.849044589788000
4	0.997556724295629	39	0.950586688832924	4	0.985250440649378	38	0.846596147659844
5	0.996605508999941	40	0.949762131264792	5	0.973615785111434	39	0.842864058041295
6	0.995230490593629	41	0.948080680583012	6	0.969824675731752	40	0.836763812830651
7	0.995162305666409	42	0.947699412106515	7	0.966228748276795	41	0.836460586682033
8	0.994284362831949	43	0.947451208722103	8	0.964155968078352	42	0.834937904285384
9	0.993322414811287	44	0.947231579767335	9	0.956206613376562	43	0.833580249813987
10	0.992261597937531	45	0.945442247668075	10	0.954784271592710	44	0.832413372748112
11	0.991459051071421	46	0.944100333413216	11	0.952086101420199	45	0.827214552369898
12	0.989346319391427	47	0.942984442265687	12	0.950122912767905	46	0.819465929676375
13	0.988010764601763	48	0.942797033727944	13	0.949945467709337	47	0.813425121556361
14	0.986626527206828	49	0.942204832610653	14	0.946678685189613	48	0.813372184247276
15	0.986565828345420	50	0.940474059170603	15	0.946541365333835	49	0.812630914730370
16	0.986128910950480	51	0.937675862141498	16	0.936667449669251	50	0.804530454349514
17	0.985366202446807	52	0.935973553971808	17	0.929494285707752	51	0.803692348347741
18	0.984175213865126	53	0.935730848671805	18	0.926996160264470	52	0.795530338165073
19	0.980805439154503	54	0.935560846037625	19	0.925721345253192	53	0.793399733255241
20	0.976641273603063	55	0.934596232633657	20	0.924646560608404	54	0.771027043376220
21	0.973266955781000	56	0.934548115691230	21	0.918676614002446	55	0.769174645327126
22	0.968724975814101	57	0.933974896367836	22	0.915592614360622	56	0.760453614363145
23	0.968059378350914	58	0.933489620572874	23	0.912438711690228	57	0.753696957145067
24	0.966656042565537	59	0.931244615548303	24	0.904941844250588	58	0.753077379873493
25	0.965467906380102	60	0.929079045353912	25	0.903714438847805	59	0.746233717818075
26	0.965408679697323	61	0.928726199653537	26	0.896703367102109	60	0.742307028845762
27	0.963696183301847	62	0.927702355155495	27	0.894643781121927	61	0.736033644402458
28	0.962312930036645	63	0.927622220954611	28	0.892306645176565	62	0.733543469862237
29	0.961606228708315	64	0.922162035618891	29	0.883031650791335	63	0.725141373728190
30	0.960807888919022	65	0.921705548028707	30	0.881606027797534	64	0.724854248077854
31	0.960466085068858	66	0.966731453160856	31	0.881592007051976	65	0.724745309388440
32	0.959998205152784	67	0.965006588368559	32	0.880927390340042	66	0.914037370558826
33	0.959962270067613	68	0.961735399458518	33	0.880089161965772	67	0.886040303663269
34	0.958512404599157	69	0.959534267923949	34	0.870996737567085	68	0.883382873373419
35	0.958268012602857					69	0.883200591068961

IV. CONCLUSION AND FUTURE SCOPE

A novel approach of direct load flow technique has been proposed using only voltage stability index for 69 and 33 bus system. The most sensitive node is found out. The results shows and improvement over existing techniques and in future other algorithms will be implemented for constant load also. A new formula of voltage stability index is proposed in this thesis work to compute the most sensitive node of radial distribution network without reducing the network. In this proposed technique, the most sensitive node and the node having the minimum voltage are identical that have been demonstrated

After carrying research work in voltage stability analysis of distribution systems, the following guidelines seem to be worth pursuing in this area: 1. Fuzzy voltage stability analysis. 2. Voltage stability analysis using bifurcation technique.

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