Research Article

Novel Contingency Analysis of Radial Distribution System with Distributed generation

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Abstract: Contingency analysis is one of the tools in smart distribution management system to analyze the contingencies, associated violations of line currents, bus voltages and power flows. In this paper, distribution power flow method using superposition principle is implemented to observe the contingencies under different loading conditions. The results are analyzed by placing distributed generation sources at various buses for different loadings. Contingency ranking is evaluated based on performance indices determining line over loading and bus voltage violations. The proposed method is illustrated through simulations of loaded 33-bus radial distribution system.

Keywords: Contingency Analysis, Distributed Generation (DG), Performance index, Radial distribution network(RDN)

1. Introduction

Power supply outages in electric grids of low (LV) and medium (MV) voltages lead to a loss of power by consumers. Power outage significantly affects the distribution system reliability and results in technological process violations leading to financial losses. Present distribution systems are vast and complex with integration of renewable energy resources. In real-time it becomes difficult to monitor and control remotely during faults and other emergencies. Contingency analysis is one of the tools in smart distribution networks which provide information to the operators regarding the consequences of any power system component outage on line flows and bus voltages. It is a measure of power system security. Identifying the impact of contingencies in a distribution network helps the system planner to divert the power by maintaining redundancy in the number of feeders.

Generally, contingency analysis is performed for transmission systems and distribution networks are considered as load injections i.e. fixed load at transmission buses. But, with accretion of distributed energy resources there are variations in power output and uncertainty in load demand. The presence of distributed energy resources has considerable impact on the flow of fault currents. Any outage seen as safe by transmission system operator may become critical due to unpredicted change in load at any bus for a distribution system augmented by DG. Therefore, a contingency analysis considering the active power flow of distribution networks is essential in smart grids.

The contingency analysis of distribution systems with DG helps in identifying the following

1. Contingency ranking of the distribution bus
2. The controlled islanding of the distribution network
3. Power supply capability limit under the micro-grid /smart operation.
4. Protective devices ratings/setting.
5. Power flows in the lines during micro-grids operating under islanded mode of operation.

Power flow methods give best results in contingency analysis. Repeated power flow technique is utilized in [1] to identify the critical voltage buses which are locations of DG installations. Probabilistic performance index is utilized in [2] for selection and ranking of contingencies. AC load flow method is applied to IEEE 24 bus transmission system in [3] to evaluate performance index for contingency ranking. Coordinated load flow which considers the impact of distributed generation on transmission system was proposed by the authors [4]. In this method sensitive load buses are selected and the effect of each outage is analyzed. This method signifies the importance of coordination between transmission and distribution system operators. Newton- Raphson method distribution load flow is utilized to analyze contingency in 33 kV distribution networks in [5]. Voltage violations at various buses and the performance indices were determined using this method. Shunt compensation is applied to improve the system performance of the network. Genetic algorithm-based topology distribution load flow is considered by authors in [6] for optimal placement and sizing of embedded generation. The impact of embedded generation is evaluated before and after contingency. An integrated algorithm with neural networks and stochastic Frontier analysis is implemented for transmission system in [7] to determine security and economic indices for ranking contingencies. Newton-Raphson based load flow method is implemented in [8] for standard 5 and 6 bus power system to analyze the contingencies. Modified backward - forward is implemented for 33 bus distribution network in [9] and the efficacy of method is compared with Newton- Raphson method. An algorithm is proposed by authors in [10] to form controlled islands in autonomous micro grid to analyze voltage variations and distribution losses. The optimal placement and sizing of distributed generation with change in loading condition due to contingency is determined by the authors using unbalanced power flow software [11]. The effect of contingency considering reconfiguration and distributed generation is analyzed by the authors [12].

The paper has been organized as follows: section 2 presents distribution power flow solution using Superposition theorem. Section 3 represents contingency analysis with and without DG. Results are presented in section 4 and conclusions are discussed in section5.

2. Power Flow Solution with Dg Using Superposition Theorem

There are many distribution power flow methods available in literature [13-15], [17-19]. Power flow solution of distribution network with DGs using superposition principle [16] is implemented in this paper. According to this method, the distribution system operating with DG is dissolved into two systems: system 1, with main generator switched on, and DGs switched off and system 2, only DGs operate and main generators switched off.

The algorithmic steps of power flow:

Step-1: From the topological line data of the distribution network compute the branch to bus incidence matrix (BBIM) and primitive impedance matrix with the DG location at Bus-1. [B] = [BBIM] × [Load currents]

Step-2: Form the modified BBIM for the DG located at Bus-8, by modifying the Rows 1 to 7 of BBIM by negating all the row elements, i.e make 0 element as -1 and 1 element as 0, use this MBBIM to compute the new branch currents as [Bnew] = [MBBIM] × [Load currents]

Step-3: Now as per the superposition principle compute the net current due to both the DG-1 and DG-8 by adding both the computed branch currents in all the branches of the distribution network.

Step-4: From the computed branch currents the voltage drops of each branch are computed as $[\Delta V_1] = [BBIM]^T \times [Z] \times [B]$ for the case with DG at Bus-1 and $[\Delta V_2] = [MBBIM]^T \times [Z] \times [Bnew]$ for the case with DG at Bus-8.

Step-5: The Bus voltages are computed for the case-1 as

$[V'] = [V] - [\Delta V_1]$

$[V'] = [V] - [BBIM]^T \times [Z] \times [B]$

$[V'] = [V] - [BBIM]^T \times [Z] \times [BBIM] \times [\text{Load currents}]$

Similarly for the Case-2 is

$[V''] = [V] - [\Delta V_2]$

$[V''] = [V] - [MBBIM]^T \times [Z] \times [Bnew]$

$[V''] = [V] - [MBBIM]^T \times [Z] \times [MBBIM] \times [\text{Load currents}]$

with simultaneously both DGs connected at Bus-1 and Bus-8 we have Bsup = B + Bnew, from which the Bus voltages are computed at each bus as [Vsup] = [V] – [Z] × [Bsup]

The branch current equation with DG placed at Bus-1, is expressed as equation 1.

[Branchcurrent vector]=[Branch to Bus Incidence matrix]×[Load Bus currents vector] ....(1)

The flow chart representing superposition principle is shown in figure 1.

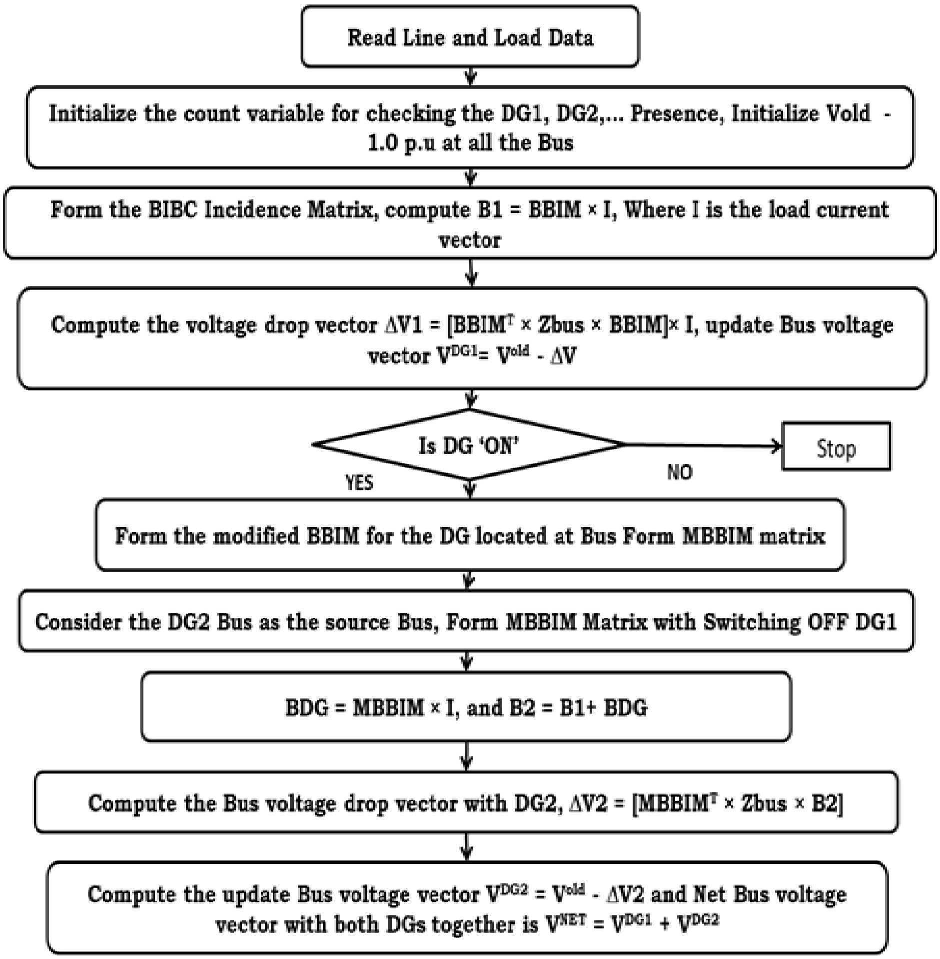

Fig 1: Flow chart of Radial distribution power flow solution with DG using superposition principle

3. Contingency analysis

In distribution system contingencies may arise due to over load, crossing feeder current flow limit, faults (loss of loads) and loss of generation. To analyze the contingency two cases are proposed:

Case1: Contingency of basic system i.e. system generators on and DGs switched off. Power is supplied by substation to the distribution system. Topological load flow method is used to obtain power flow solution and the line currents and bus voltages.

Case2: Contingency of system with DG power injections

Performance indices of voltage and power flow are calculated for various DG power injections. The severity of contingency at various buses is analyzed and most insecure bus is identified. The power flow under contingency is illustrated in figure2.

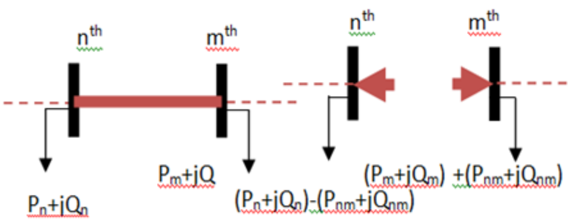

Fig 2: Contingencies (Outage of Line)

Two performance indices, voltage performance index and active power performance index are determined using following expressions (2) and (3):

Voltage Performance Index

$$PI_V = \sum_{i=1}^{n} \left[\frac{W}{2Z}\right] \left[\frac{|V_i| - |V_i^{sp}|}{\Delta V_i^{th}}\right]^{2Z} \ldots\ldots\ldots\ldots(2)$$

Where, $|V_i|$ is the magnitude of the i[th] bus voltage,

$|V_i^{sp}|$ is the magnitude of the specified voltage at the ith Bus

ΔV_i^{th} is the threshold voltage deviation at the ith Bus taking the average value of the minimum and maximum allowed voltages at that bus.

'n' is the number of buses

W is the real non-negative weigh factor (W=1)

Z is the exponent penalty factor (Z =1)

Here to calculate ΔV_i^{th} ,maximum voltage limit is 1.05 p.u and minimum voltage limit is 0.95 p.u since ±5% deviation in voltage is allowed. This voltage performance index will give the information about the change in voltage at each and every bus.

Active Power Performance Index

$$PI_{MW} = \sum_{b=1}^{N_b} \left[\frac{W}{2Z}\right] \left[\frac{P_b}{P_b^{max}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, P_b is the power flow through branch 'b'

P_b^{max} is the maximum capacity of power flow through the branch 'b'

'Nb' is the number of branches

W is the real non-negative weigh factor (W=1)

Z is the exponent penalty factor (Z =1)

The flow chart representing contingency analysis of RDN is represented in figure 3.

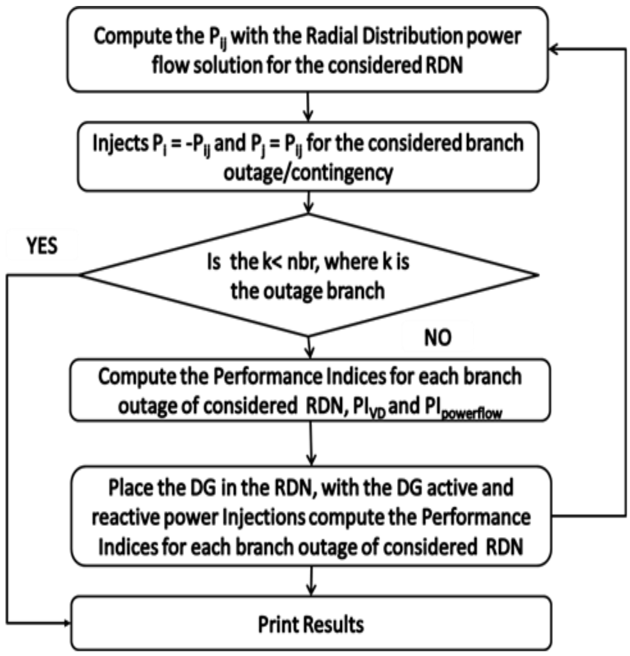

Figure 3: Flow chart of contingency analysis of RDN with and without DG

4. Results And Discussions

A 33 bus distribution system as shown in figure 4 has been considered to evaluate the proposed method. This test system considered has 100 MVA as base MVA and total initial substation load chosen is 3750+j*2300.

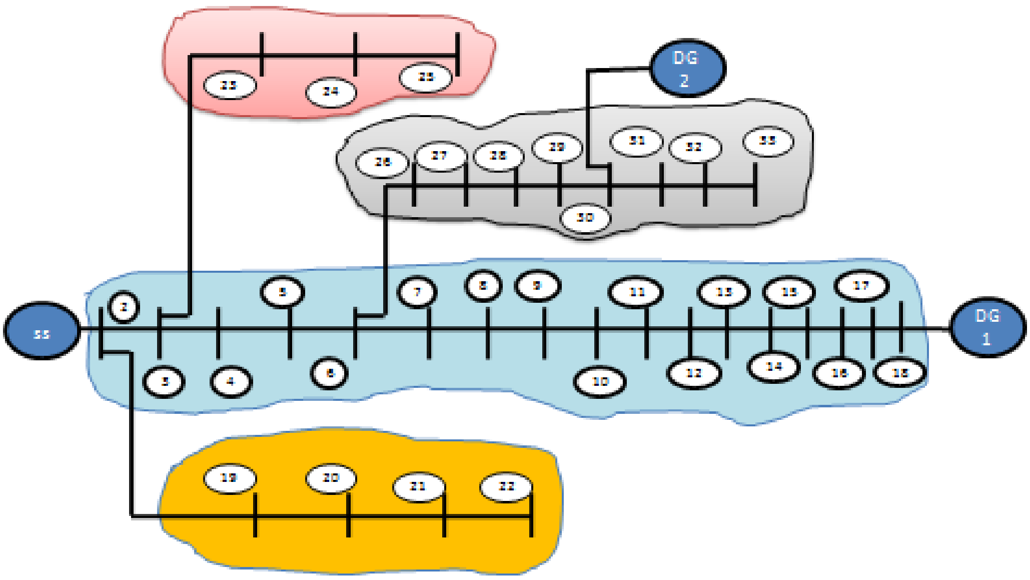

Figure 4: Radial distribution system with DG

With contingencies in each branch the substation total power supply and the corresponding total system active and reactive power losses are shown in Table1

Table1: Active and reactive power loss with contingency

Branch Number	Substation Power	TP_{ss}	TQ_{ss}	TP_{LOSS}	TQ_{LOSS}
Initial	0.371+0.23i				
1	0.361+0.22i	0.36	0.22	0.01	0.006
2	0.329+0.20i	0.32	0.20	0.041	0.027
3	0.306+0.18i	0.30	0.18	0.065	0.047
4	0.295+0.17i	0.29	0.17	0.076	0.057
5	0.284+0.16i	0.28	0.16	0.084	0.064
6	0.271+0.15i	0.27	0.15	0.100	0.075
7	0.253+0.14i	0.25	0.14	0.118	0.084
8	0.249+0.14i	0.24	0.14	0.121	0.085
9	0.246+0.14i	0.24	0.14	0.125	0.087
10	0.244+0.14i	0.24	0.14	0.127	0.088
11	0.240+0.13i	0.24	0.13	0.130	0.091
12	0.237+0.13i	0.23	0.13	0.134	0.093
13	0.228+0.12i	0.22	0.12	0.143	0.100
14	0.224+0.12i	0.22	0.12	0.147	0.100
15	0.220+0.12i	0.22	0.12	0.151	0.101
16	0.215+0.12i	0.21	0.12	0.156	0.103
17	0.207+0.12i	0.20	0.12	0.164	0.106
18	0.210+0.13i	0.21	0.13	0.161	0.098
19	0.198+0.12i	0.19	0.12	0172	0.104
20	0.188+0.12i	0.18	0.12	0.183	0.109
21	0.178+0.11i	0.17	0.11	0.193	0.113
22	0.174+0.11i	0.17	0.11	0.197	0.111
23	0.128+0.09i	0.12	0.09	0.242	0.133
24	0.084+0.07i	0.08	0.07	0.287	0.155
25	0.076+0.07i	0.07	0.07	0.295	0.158
26	0.072+0.06i	0.07	0.06	0.298	0.161
27	0.069+0.06i	0.06	0.06	0.302	0.162
28	0.06+0.061i	0.06	0.06	0.311	0.168
29	0.04+0.003i	0.04	0.00	0.327	0.226

30	0.031-0.019i	0.03	-	0.339	0.231
31	0.012-.0117i	0.01	-	0.358	0.241
32	0.007-.0155i	0.00	-	0.363	0.245

Voltage and current profiles of test system under contingencies at strategic branches of the distribution feeders with and without DG power injections are represented in figures5 to 9.

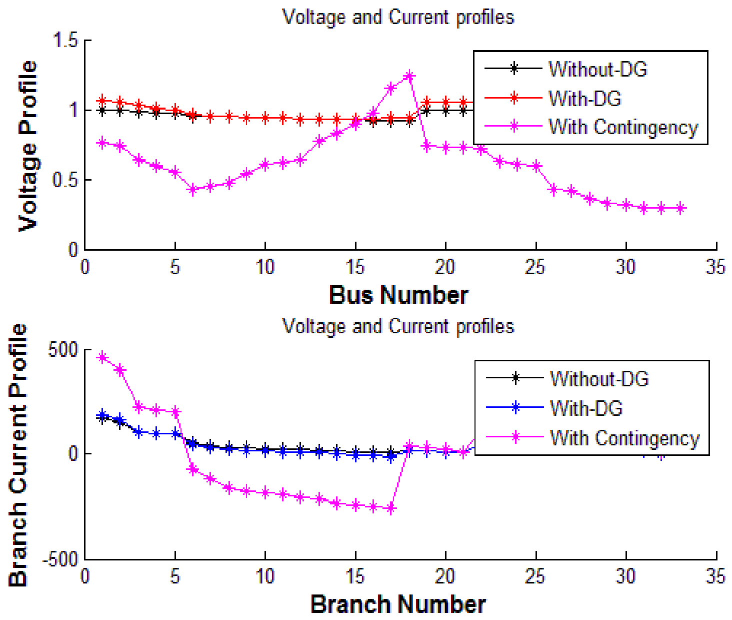

Figure 5: Voltage and current profile during contingency in branch-3

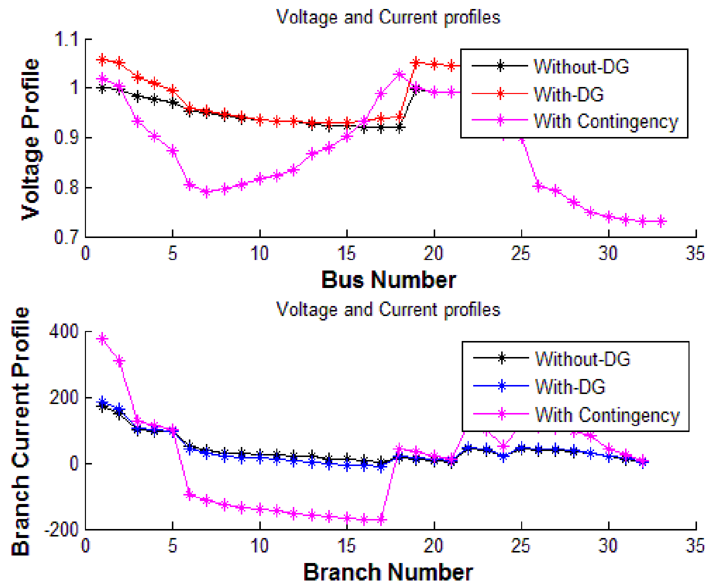

Figure6: Voltage and current profile during contingency in branch 17

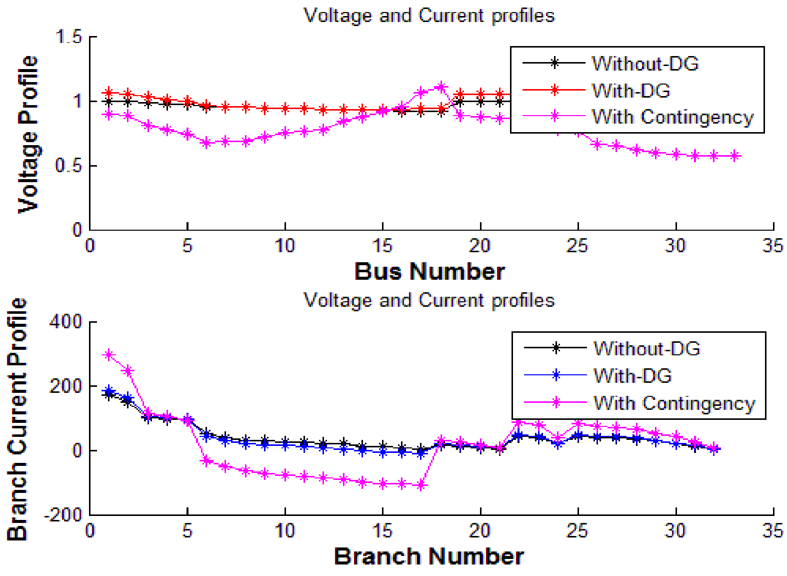

Figure 7: Voltage and current profile during contingency in branch 18

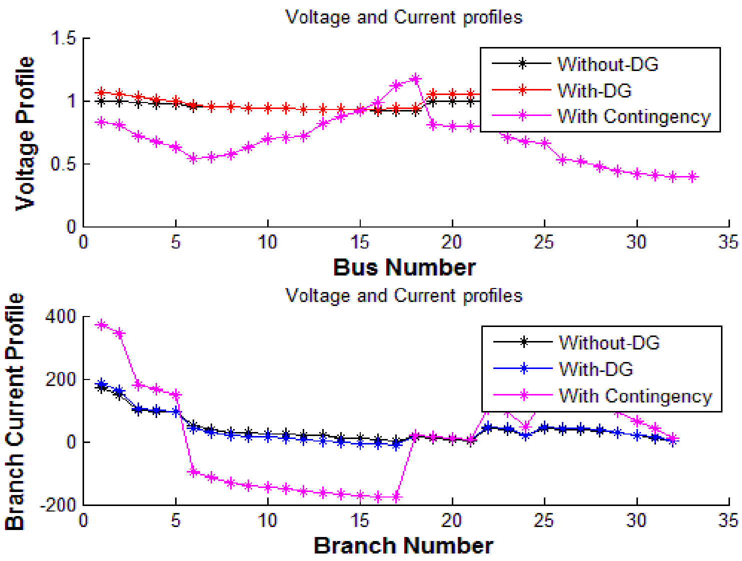

Figure 8: Voltage and current profile during contingency in branch 22

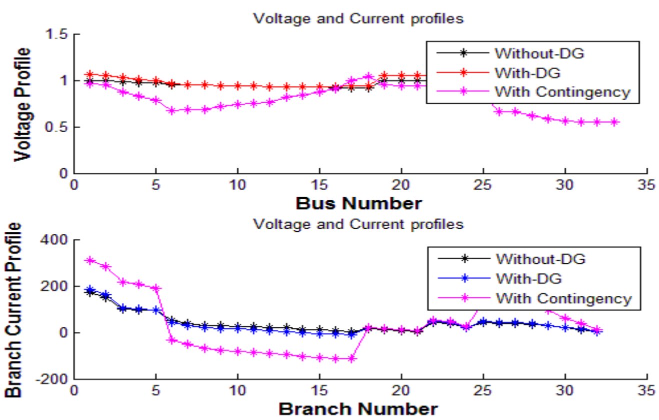

Figure 9: Voltage and current profile during contingency in branch 25

It is observed from the branch current profiles of the RDS during the contingencies at the branches 3, 17, 18, 22, 25 that the magnitude of current variation is maximum of 500, 400, 300, 400, 300 A respectively in the 2nd Branch and reversal of current is in branches 6-7-8-9-10-11-12-13-14-15-6-17 with DG location at Bus-18. The voltage profile of the RDS during the contingencies at the branches 3, 17, 18, 22, 25 is violating the minimum limit of 0.95 p.u at all the system buses

The impact of contingencies on the system loads and the feeders with and without DG have been analyzed and the contingency ranking of the branches based on criterion of performance index (the voltage deviation and the Power flow) for different cases in each branch have been presented in tables 2 and 3 .

Case1: Contingency Ranking of buses with X=0 in the distribution lines

Case2: Contingency Ranking of buses with 15% of the total load injection DG at Bus18

Case3: Contingency Ranking of buses with 20% of the total load injection by DG at Bus18

Case 4: Contingency Ranking of buses with 25% of the total load injection by DG at Bus-18

Case 5: Contingency Ranking of buses with 1.2 times loading, and 15% of the total load injection DG at Bus18

Case 6: Contingency Ranking of buses with 15% of the total load injection DG at Bus22

Table2: Contingency Ranking of buses with X=0 (case1) in the distribution lines

Rank	PI_V	Bus No	PI_{PF}	Bus No	PI_V+PI_{PF}	Bus No
1	61.4082	3	1.5459	4	62.9526	3
2	60.5633	4	1.5444	3	62.1092	4
3	58.6365	5	1.4539	5	60.0904	5
4	56.6928	6	1.3699	6	58.0628	6
5	52.1545	7	1.1711	7	53.3256	7
6	47.1484	8	1.0335	2	48.1297	8
7	46.4398	2	0.9812	8	47.4733	2
8	45.1347	9	0.9112	9	46.0459	9
9	43.9040	10	0.8694	10	44.7734	10
10	43.0581	11	0.8392	11	43.8974	11
11	42.1228	12	0.8091	12	42.9319	12
12	41.3771	13	0.7852	13	42.1623	13
13	40.3188	14	0.7511	14	41.0699	14
14	39.7006	15	0.7351	15	40.4356	15
15	39.3062	16	0.7236	16	40.0298	16
16	39.1189	17	0.7184	17	39.8373	17
17	39.0823	18	0.7172	18	39.7995	18
18	38.0211	19	0.6833	19	38.7044	19
19	35.8691	20	0.6238	20	36.4929	20
20	33.6781	21	0.5638	21	34.2419	21
21	31.6015	22	0.5091	22	32.1106	22
22	29.8806	23	0.4596	23	30.3402	23
23	22.7082	24	0.2810	24	22.9892	24
24	16.2193	25	0.1523	25	16.3716	25
25	14.8678	26	0.1292	26	14.9971	26
26	14.3034	27	0.1178	27	14.4212	27
27	13.7934	28	0.1085	28	13.9018	28
28	12.7395	29	0.0863	29	12.8257	29
29	10.6458	30	0.0201	30	10.6659	30
30	9.2818	31	0.0121	31	9.2938	31
31	7.5397	32	0.0057	32	7.5454	32
32	7.0805	33	0.0052	33	7.0858	33

Table 3: Contingency ranking of buses with DG power injection of 20 % of the total system power at 18th Bus (Case3)

Rank	PI_V	Bus No	PI_{PF}	Bus No	PI_V+PI_{PF}	Bus No
1	199.667	6	5.7241	6	205.391	6
2	195.291	5	5.4641	5	200.755	5
3	193.302	7	5.4008	7	198.703	7
4	185.811	4	4.9090	4	190.720	4
5	178.929	8	4.6647	8	183.594	8
6	169.772	9	4.1837	9	173.955	9
7	164.887	3	3.8568	10	168.636	3
8	163.133	10	3.749	3	166.990	10
9	158.014	11	3.622	1	161.636	11
10	153.244	12	3.418	2	156.663	12
11	149.191	13	3.250	3	152.442	13
12	144.534	14	3.071	4	147.605	14
13	141.658	15	2.952	5	144.610	15
14	139.606	16	2.872	6	142.478	16
15	138.420	17	2.824	7	141.244	17
16	137.937	18	2.803	8	140.740	18
17	130.985	19	2.560	9	133.545	19
18	123.751	20	2.300	20	126.052	20
19	116.771	21	2.063	21	118.834	21
20	111.366	2	1.8510	22	112.977	2
21	110.158	22	1.611	2	112.009	22
22	102.0348	23	1.5964	23	103.631	23
23	82.1660	24	1.0498	24	83.2158	24
24	62.8455	25	0.6225	25	63.4681	25
25	56.9974	26	0.4985	26	57.4958	26
26	55.7515	27	0.4706	27	56.2221	27
27	55.3163	28	0.4594	28	55.7757	28
28	53.1731	29	0.4133	29	53.5864	29
29	39.4199	30	0.1764	30	39.5963	30
30	35.7125	31	0.1304	31	35.8429	31
31	30.8569	32	0.0812	32	30.9381	32
32	29.3175	33	0.0685	33	29.3860	33

Contingency analysis based on performance indices for main feeder and laterals is tabulated in table 4.

Table 4: Contingency analysis of test system

Scenario	Contingency Analysis with Branch-Rank number							
	Main Feeder		Lateral-1		Lateral-2		Lateral-3	
	PI-VD	PI-PF	PI-VD	PI-PF	PI-VD	PI-PF	PI-VD	PI-PF
Case-1	3-1	4-1	18-17	18-17	22-21	22-21	25-24	25-24
Case-2	5-1	5-1	18-16	18-16	22-21	22-21	25-24	25-24
Case-3	6-1	6-1	18-16	8-16	22-21	2-21	25-24	25-24
Case-4	7-1	7-1	18-16	8-16	22-20	22-20	25-24	25-24
Case-5	7-1	7-1	18-16	18-16	22-20	22-20	25-24	25-24
Case-6	6-1	6-1	18-16	18-16	22-20	22-20	25-24	25-24

The following observations are made from above table:

1. It is observed from table 3 that the main feeder branches are ranked as most severe from the distribution secure operation point of view.
2. Starting branch of the laterals is much affected due to the outages in the lateral branches.
3. With the increase in DG power injection at 18th Bus, the power flow in the branch-8 of the main feeder is getting over loaded.
4. There is no much effect of change in the ranking priority with the placement of DG at the 22nd Bus.
5. The most insecure bus is 17th bus and 5th bus and the most secure bus is 2nd bus and 33rd bus with the DG power injections varying from 50% to 5% of the total load of the system for the case with voltage as performance index.

There is an increase in the severity of contingency ranking of 2nd, 3rd, 4th, 8th and 9th bus with the reduction in the DG power injection and vice-versa, for the case with voltage and line power flow as performanceiIndex. Also it has been observed that the 2nd bus is more sensitive to variations with the DG power Injections.

5. Conclusions

Here the authors proposed a novel contingency analysis of radial distribution using superposition principle in the presence of distributed generation. The developed algorithm has been tested on a standard radial distribution system and the results obtained with the superposition principle in the presence of DG have been verified. The obtained contingency ranking of the branches helps the system operator and the planner to securely operate the system which makes the uninterrupted power supply to the consumers. Also the system planner can provide the backup protection of the distribution transformers, feeders and the regulating transformers based on the simulation results obtained during different operating conditions of the DG power injections

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