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APPLICATIONS AND RESULTS

6.1. Test Systems

The proposed procedure (AOA) is applied on 34-bus standard radial distribution system and East Delta Network (EDN) radial distribution system as a part of the Unified Egyptian Network (UEN) in order to solve the optimal DGs and capacitors placement problem. The test systems data is shown in Appendix A. The results are compared with those obtained using other reported methods.

The proposed DG units can be classified into two types based on real and reactive power delivering as follows:

- DG injects only active power (i.e., operating at unity power factor), such as fuel cells, photovoltaic and micro-turbines.
- DG injects both active and reactive power (i.e., operating at power factor < 1), such as wind turbines and induction generators.

One type of capacitors is considered, which is fixed capacitors.

6.2. Case Studies

The proposed procedure is applied on the test systems with four different cases are:

Case 0: without DGS and Capacitors (BFS algorithm results).

Case 1: With only DGs operating at unity power factor (p.f.), means that only active power injections.

Case 2: With only DGs operating at p.f. = .9 , means that active and reactive power injections.

Case 3: With only capacitors, means that only reactive power injections.

Case 4: with both DGs and capacitors.

6.3. Assumptions and Limits

The assumptions and the limits of constraints are considered as follows:

- The minimum and maximum limits of DG active power are 500 and 2000 kW, respectively.
- The minimum and maximum limits of capacitors are 150 and 1200 kVAR, respectively.
- The operating p.f. of DGs is .9 in case 2, while it is unity in all other cases.
- The minimum and maximum limits of voltage magnitude are 0.95 and 1.05 p.u., respectively.
- The maximum number of DGs possible locations (NDGmax) is 4.
- The maximum number of capacitors possible locations (NCmax) is 4.

6.4. Results

The proposed procedure is used to obtain the optimal DGs and capacitors placement using MATLAB code. The results of the proposed procedure are compared with the results obtained using other methods.

6.4.1. Total power losss minimization

6.4.1.1. 34-bus radial distribution system

Tables 1.1-1.5 show the optimal locations and sizes of DGs and the capacitors required to reduce the total active power loss as an objective function for cases 1-5 for the 34-bus test system. Moreover, a comparison between the proposed procedure and other methods is presented.

Table 1.1 A comparison between the power loss minimization using the proposed procedure with other methods using only the DGs at unity power factor (case 1) for 34-bus test system

Items	Un-compensated (Case 0)	Compensated (Case 1)									
		DPS [10]		Analytical Method [11]		MBFO [12]		GA [13]		Proposed procedure	
Optimal locations and sizes of DGs (kW)	-	27	2500	21	2884.8	21	2951.7	4	500	23	1847.5
		-	-	-	-	-	-	7	500	31	1152.5
		-	-	-	-	-	-	17	500	-	-
		-	-	-	-	-	-	21	500	-	-
		-	-	-	-	-	-	25	500	-	-
		-	-	-	-	-	-	28	500	-	-
Total size	-	2500		2884.8		2951.7		3000		3000	
Total losses (kW)	**221.752**	**118.8**		**93.838**		**93.751**		**83.84**		**74.416**	
TVD	0.0483	.0086		.0079		.0074		.0108		.0046	
Minimum bus voltage(p.u.)	0.9417 (#27)	0.9750 (#34)		0.9773 (#34)		0.9777 (#34)		0.9723 (#27)		0.9832 (#27)	
Maximum bus voltage(p.u.)	0.9941 (#2)	1.0034 (#27)		0.9971 (#2)		0.9971 (#2)		0.9972 (#2)		0.9972 (#2)	
Overall power factor	0.85	0.5967		0.5205		0.5058		0.4949		0.4949	

Table 1.1 presents the optimal solution for case 1 using the proposed procedure, when only active power from DGs is injected. It can be observed that, the initial power loss without DGs is reduced from 221.752 kW to 74.4167 kW after placement of DGs. The optimal locations of DGs are at buses {23,31} with total rating power 3000 kW. Moreover, the minimum and maximum voltage magnitudes are improved.

Table 1.2 A comparison between the power loss minimization using the proposed procedure with other methods using only the DGs at 0.9 power factor (case 2) for 34-bus test system

Items	Un-compensated (Case 0)	Compensated (Case 2)				
		Analytical Approach [18]			**Proposed procedure**	
Optimal locations and sizes of DGs (kW, kVAR)	-	**Locations**	**DG Size (kW)**	**-**	**Locations**	**DG size (kW)**
		20	3231.8	-	23	1863.3
		-	-	-	10	1136.7
		-	-	-		
Total size	-	-	3231.8	-	-	3000
Total losses (kW)	**221.752**	**49.415**			**25.348**	
TVD	0.0483	.004			.0023	
Minimum bus voltage(p.u.)	0.9417 (#27)	0.9832 (#34)			0. 9888 (#27)	
Maximum bus voltage(p.u.)	0.9941 (#2)	1.0015 (#20)			0.9978 (#2)	
Overall power factor	0.85	0.85			. 7552	

Table 1.2 presents the optimal solution for case 2 using the proposed procedure, when active and reactive power from DGs are injected. It can be observed that, the initial power loss without compensation is reduced from 221.752 kW to 25.348 kW after placement of DGs. The optimal locations of DGs are at buses {23,10} with total rating power 3000 kW and 1452.9 kVAR. Moreover, the minimum and maximum voltage magnitudes are improved after placement of DGs.

From these Tables, the total power loss, the total active and reactive power injections using the proposed procedure are lower than that obtained using the other methods. Case 2 gives better results than other cases. Moreover, the overall power factor is improved after placement of DGs and capacitors. In addition, the overall power factor are within permissible limits. Therefore, this comparison reflects to the great capability of the proposed procedure to find the optimal locations and sizes of DGs and capacitors in order to reduce the total power loss and improve the system reliability.

Table 1.3 A comparison between the power loss minimization using the proposed procedure with other methods using only the capacitors (case 3) for 34-bus test system

Items	**Un-compensated (Case 0)**	**Compensated (Case 3)**									
		PGSA [14]		**BFA [15]**		**GA [16]**		**APSO [17]**		**Proposed procedure**	
Optimal locations and sizes of capacitors (kVAR)	-	19	1200	9	600	7 buses	1629	19	1050	18	896.88
		20	200	22	900			25	750	9	758.562
		22	639	-	-			-	-	24	862.755
Total size	-	2039		1500		1629		1800		2482.5	
Total losses (kW)	**221.752**	**169.167**		**169.07**		**168.955**		**168.023**		**160.4252**	
TVD	.0483	.0368		.0394		.0408		.0375		.0344	
Minimum bus voltage(p.u.)	0.9417 (#27)	0.9492 (#27)		0.9503 (#27)		0.9491 (#27)		0.9416 (#27)		0.9503 (#27)	
Maximum bus voltage(p.u.)	0.9941 (#2)	0.995 (#2)		0.9948 (#2)		0.9948 (#2)		0.9949 (#2)		0.9952 (#2)	
Overall power factor	0.85	0.9842		0.9588		0.9658		0.9738		0.9965	

Table 1.3 presents the optimal solution for case 3 using the proposed procedure, when only reactive power from capacitors is injected. It is clear that, the initial power loss without compensation is reduced from 221.752 kW to 160.4252 kW after placement of capacitors. The optimal locations of capacitors are at buses {18,9,24} with total rating power 2482.5 kVAR. Moreover, the minimum and maximum voltage magnitudes and overall system power factor are improved.

Table 1.4 A comparison between the power loss minimization using the proposed procedure with other methods using DGs at unity power factor and capacitors (case 4) for 34-bus test system

Items	Un-compensated (Case 0)	Compensated (Case 4)	
		Proposed procedure	
Optimal locations and sizes of DGs (KW)	-	9	952.8
		21	1125.5
		25	921.6
Total DGs size		3000	
Optimal locations and sizes of capacitors (KVAR)		7	1110.4
		24	816.6
Total capacitors size	-	1927	
Total losses (kW)	**221.752**	**18.15**	
TVD	.0483	.0023	
Minimum bus voltage(p.u.)	0.9417 (#27)	0.9892 (#33)	
Maximum bus voltage(p.u.)	0.9941 (#2)	0.998 (#2)	
Overall power factor	0.85	0.8656	

Table 1.4 presents the optimal solution for case 4 using the proposed procedure, when active power from DGs is injected and reactive power is injected from capacitors . It can be observed that, the initial power loss without compensation is reduced from 221.752 kW to 18.15 kW after placement of DGs and capacitors. The optimal locations of DGs are at buses {9,21,25} with total rating power 3000 kW and the optimal locations of capacitors are at buses { 7,24} with total power rating 1927 kVAR. Moreover, the minimum and maximum voltage magnitudes are improved after placement of DGs and capacitors.

Table 1.5 A comparison between the power loss minimization using the proposed procedure with other methods using DGs at .9 power factor and capacitors (case 5) for 34-bus test system

Items	Base case	Case 5	
		FPA [9]	Proposed method
DG size (kW, kVAR) and location	-	2086, 1292.8 (#26)	799.3, 387.09 (#31), 946.5, 458.37 (#24), 1254.2 , 607.39 (#21)
Capacitor size (kVAR) and location	-	1250 (#26)	365.568 (#8)
Total size of DGs (kW, kVAR)	-	2086, 1292.8	3000, 1452.86
Total size of capacitors (kVAR)	-	1250	1112.9
f_1 [Loss (kW)]	**221.752**	**58.8298**	**17.1153**
TVD	.0483	.007	.0021
Min. voltage (p.u.)	0.9417 (#27)	0.9751 (#34)	0.99 (#12)
Overall p.f.	0.85	0.8436	.8405

Table 1.5 presents the optimal solution for case 5 using the proposed procedure, when active power and reactive power from DGs are injected and reactive power is injected from capacitors . It can be observed that, the initial power loss without compensation is reduced from 221.752 kW to 17.11 kW after placement of DGs and capacitors. The optimal locations of DGs are at buses {31,24,21} with total rating power 3000 kW and the optimal locations of capacitors are at buses { 8} with total power rating 1112.9 kVAR. Moreover, the minimum and maximum voltage magnitudes are improved after placement of DGs and capacitors.

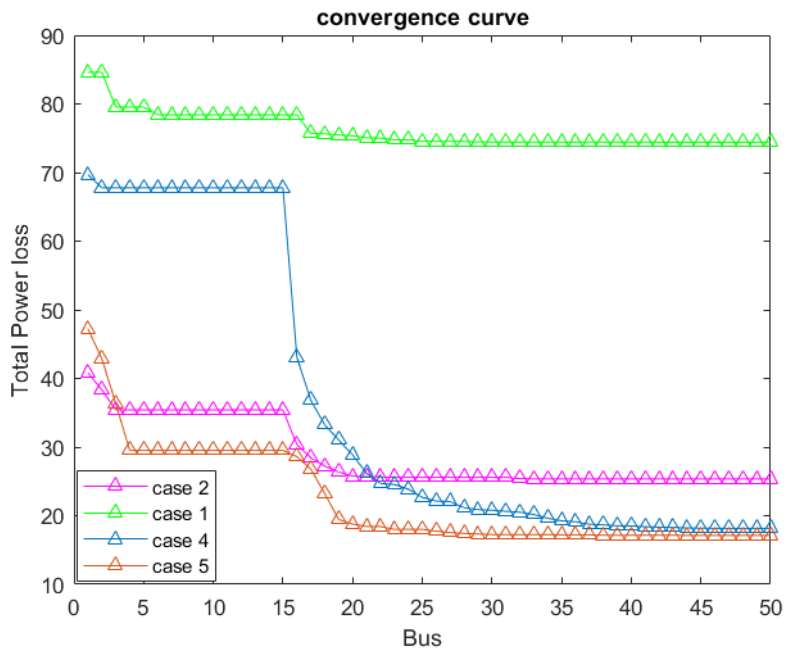

Fig. 1.1

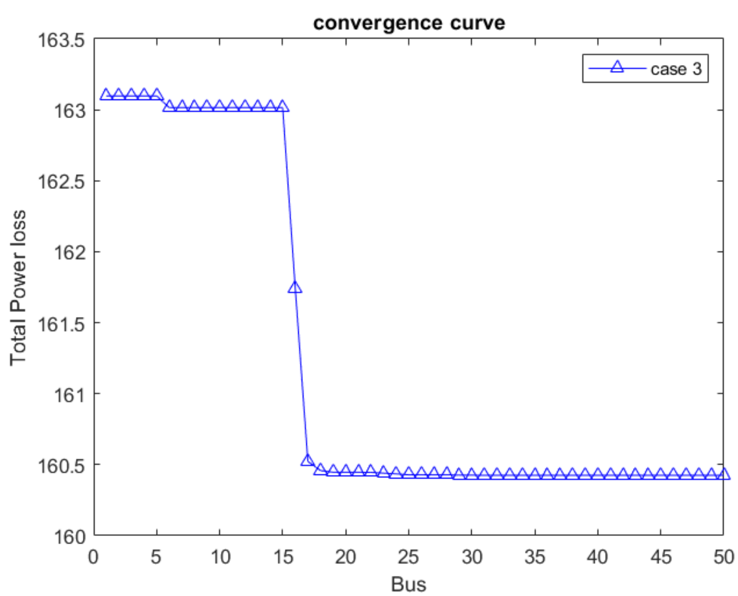

Fig. 1.2

Fig. 1.1 and Fig. 1.2 shows the convergence curves of the AOA algorithm to reduce the total power loss using the DGs and capacitors for 34-bus test system. It is clear that, the AOA algorithm is able to reach the optimal solution with more accuracy and efficiency.

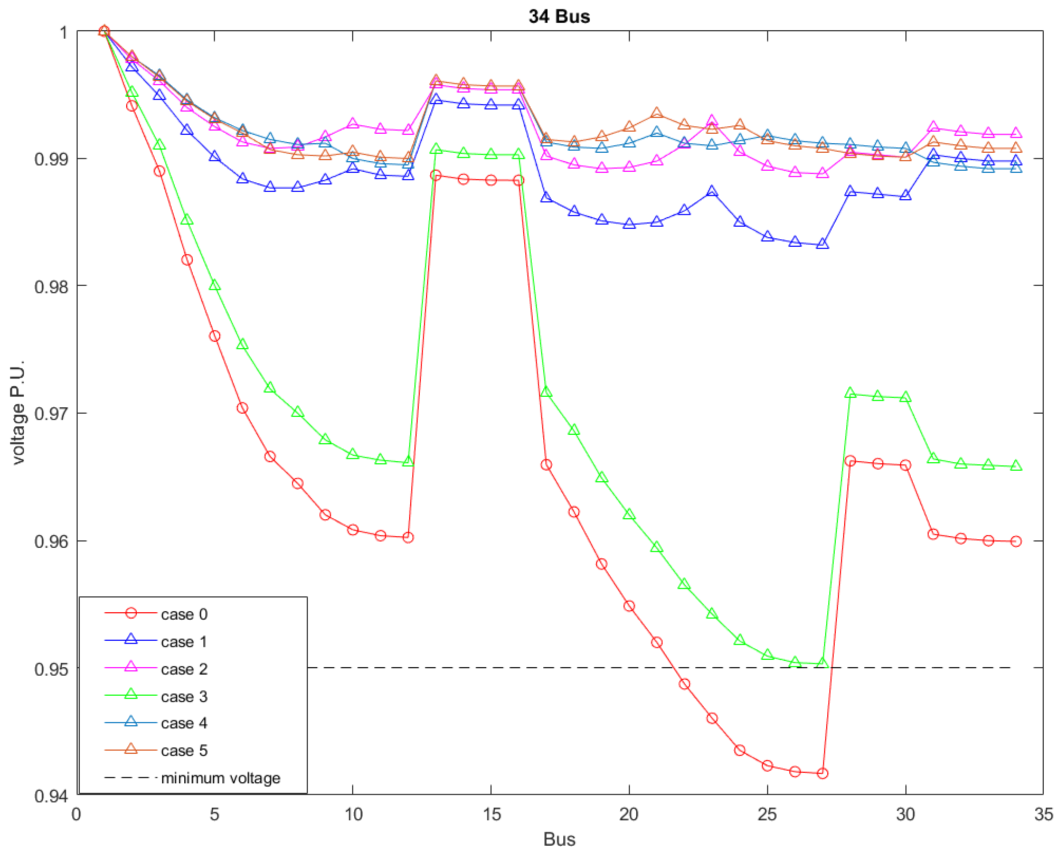

Fig. 1.3 Voltage profile at different cases for 34-bus test system

Fig. 1.3 shows the voltage profiles for cases 0-5, when the total power loss minimization is considered as an objective function. The voltage profiles are improved at cases 1-5, where the voltage profile improvement based on case 2 is better than that obtained from other cases, while the average values of voltages are 0.9658,0.9855, 0.9913, 0.9706 and 0.9895 for cases 1-5, respectively. Moreover, the minimum voltage limit is violated at buses starts from 22 to 27 in case 0.

6.4.1.2. EDN radial distribution system

Tables 1.6-1.10 show the optimal locations and sizes of DGs and the capacitors required to reduce the total active power loss as an objective function for cases 1-5 for the EDN system.

Table 1.6 Optimal locations and sizes of DGs at unity power factor using the proposed method for EDN system (case 1)

Items	**Un-compensated (Case 0)**	**Compensated (Case 1)**	
Optimal locations and sizes of DGs (kW)	-	21	1999.9
		25	2000
Total size	-	3999.9	
Total losses (kW)	**805.73**	**542.459**	
TVD	.0439	.0225	
Minimum bus voltage(p.u.)	0.9463 (#30)	0.9669 (#23)	
Maximum bus voltage(p.u.)	0.9854 (#2)	0.9874 (#2)	
Overall power factor	0.8457	0.7932	

Table 1.6 presents the optimal solution for case 1 using the proposed procedure, when only active power from DGs is injected. It can be observed that, the initial power loss without DGs is reduced from 805.73 kW to 542 kW after placement of DGs. The optimal locations of DGs are at buses {21,25} with total rating power 4000 kW. Moreover, the minimum and maximum voltage magnitudes are improved.

Table 1.7 Optimal locations and sizes of DGs at 0.9 power factor using the proposed method for EDN system (case 2)

<table>
<tr><th rowspan="2">Items</th><th rowspan="2">Un-compensated (Case 0)</th><th colspan="2">Compensated (Case 2)</th></tr>
<tr><th>Locations</th><th>DG size (kW)</th></tr>
<tr><td rowspan="3">Optimal locations and sizes of DGs (kW)</td><td rowspan="3">-</td><td>25</td><td>2000</td></tr>
<tr><td>21</td><td>2000</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Total size</td><td>-</td><td>-</td><td>4000</td></tr>
<tr><td>Total losses (kW)</td><td>805.73</td><td colspan="2">458.85</td></tr>
<tr><td>TVD</td><td>.0439</td><td colspan="2">.0193</td></tr>
<tr><td>Minimum bus voltage(p.u.)</td><td>0.9463 (#30)</td><td colspan="2">0. 9699 (#23)</td></tr>
<tr><td>Maximum bus voltage(p.u.)</td><td>0.9854 (#2)</td><td colspan="2">0.9879 (#2)</td></tr>
<tr><td>Overall power factor</td><td>0.8457</td><td colspan="2">0.8335</td></tr>
</table>

Table 1.7 presents the optimal solution for case 2 using the proposed procedure, when active and reactive power from DGs are injected. It can be observed that, the initial power loss without compensation is reduced from 805.73 kW to 458 kW after placement of DGs. The optimal locations of DGs are at buses {25,21} with total rating power 4000 kW and 1937 kVAR. Moreover, the minimum and maximum voltage magnitudes are improved after placement of DGs.

Table 1.8 Optimal locations and sizes of capacitors using the proposed method for EDN system (case 3)

Items	Un-compensated (Case 0)	Compensated (Case 3)	
Optimal locations and sizes of capacitors (kVAR)	-	26	963.8
		21	1198.9
		8	782.9
		18	1054.4
Total size	-	4000	
Total losses (kW)	**805.73**	**673.69**	
TVD	.0439	.036	
Minimum bus voltage(p.u.)	0.9463 (#30)	0.9521 (#30)	
Maximum bus voltage(p.u.)	0.9854 (#2)	0.9865 (#2)	
Overall power factor	0.8457	0.9108	

Table 1.8 presents the optimal solution for case 3 using the proposed procedure, when only reactive power from capacitors is injected. It is clear that, the initial power loss without compensation is reduced from 805.73 kW to 673.69 kW after placement of capacitors. The optimal locations of capacitors are at buses {29,20,18,27} with total rating power 3743.01 kVAR. Moreover, the minimum and maximum voltage magnitudes and overall system power factor are improved.

From these Tables, the total power loss is reduced using the proposed method. Case 2 gives the better results for the considering the objective function and constraints than that other cases. Moreover, the overall power factor is improved after placement of DGs and capacitors. In addition, the overall power factor are within permissible limits.

Table 1.9 A comparison between the power loss minimization using the proposed procedure with other methods using DGs at unity power factor and capacitors (case 4) for EDN system

Items	Un-compensated (Case 0)	Compensated (Case 4)	
		Proposed procedure	
Optimal locations and sizes of DGs (KW)	-	22	1458.3
		25	1374.3
		18	1167.4
Total DGs size		4000	
Optimal locations and sizes of capacitors (KVAR)		11	495.3
		25	1162.6
Total capacitors size	-	1657.9	
Total losses (kW)	**805.73**	**474.879**	
TVD	.0439	.0208	
Minimum bus voltage(p.u.)	0.9463 (#30)	0.9682 (#24)	
Maximum bus voltage(p.u.)	0.9854 (#2)	0.9879 (#2)	
Overall power factor	0.8457	0.8277	

Table 1.9 presents the optimal solution for case 4 using the proposed procedure, when active power from DGs is injected and reactive power is injected from capacitors . It can be observed that, the initial power loss without compensation is reduced from 805 kW to 474 kW after placement of DGs and capacitors. The optimal locations of DGs are at buses {22,25,18} with total rating power 4000 kW and the optimal locations of capacitors are at buses { 11,25} with total power rating 1657 kVAR. Moreover, the minimum and maximum voltage magnitudes are improved after placement of DGs and capacitors.

Table 1.10 A comparison between the power loss minimization using the proposed procedure with other methods using DGs at .9 power factor and capacitors (case 5) for EDN system

Items	Base case	Case 5
		Proposed method
DG size (kW, kVAR) and location	-	687.7 , 333.05 (#23), 1873.1 , 907.19 (#21), 1439.2 , 697.02 (#26)
Capacitor size (kVAR) and location	-	1200 (#18) 630.8 (#4)
Total size of DGs (kW, kVAR)	-	4000, 1937.156
Total size of capacitors (kVAR)	-	1830.8
f_1 [Loss (kW)]	**805.73**	**411.4659**
TVD	.0439	.0180
Min. voltage (p.u.)	0.9463 (#30)	0.9714 (#24)
Overall p.f.	0.8457	.8711

Table 1.10 presents the optimal solution for case 5 using the proposed procedure, when active power and reactive power from DGs are injected and reactive power is injected from capacitors . It can be observed that, the initial power loss without compensation is reduced from 805 kW to 411 kW after placement of DGs and capacitors. The optimal locations of DGs are at buses {23,21,26} with total rating power 4000 kW and 1937 kVAR and the optimal locations of capacitors are at buses { 18,4} with total power rating 1830 kVAR. Moreover, the minimum and maximum voltage magnitudes are improved after placement of DGs and capacitors.

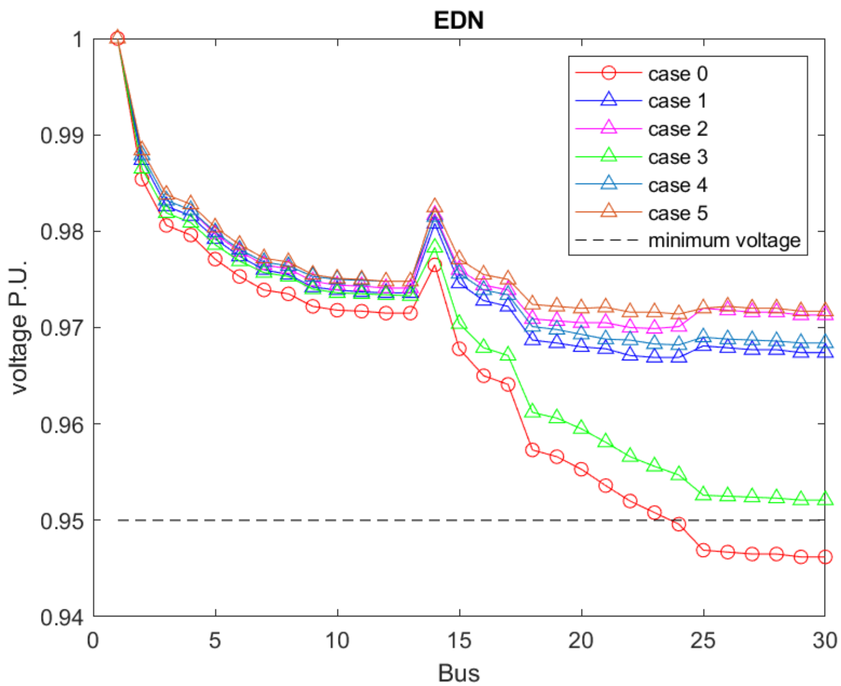

Fig. 1.4 Voltage profile for EDN system

Fig. 1.4 shows the voltage profiles for cases 0-5, when the total power loss minimization is considered as an objective function. The voltage profiles are improved at cases 1-5, where the voltage profile improvement based on case 2 is better than that obtained from other cases.

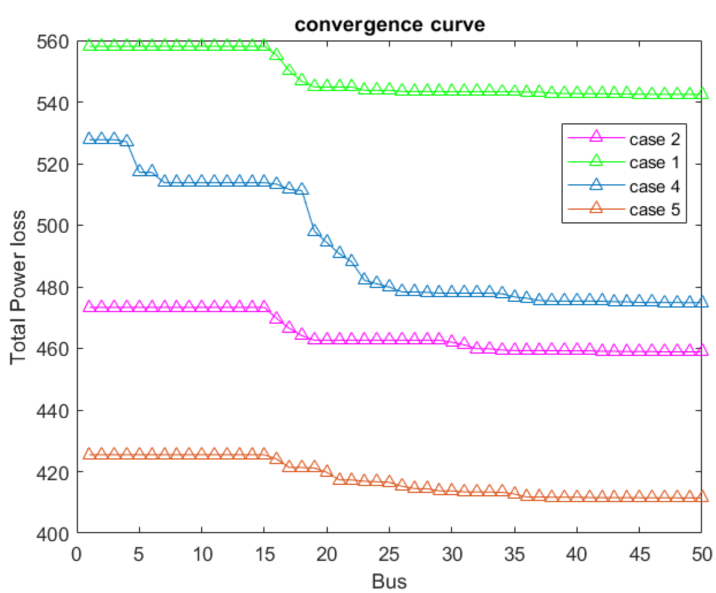

Fig 1.5

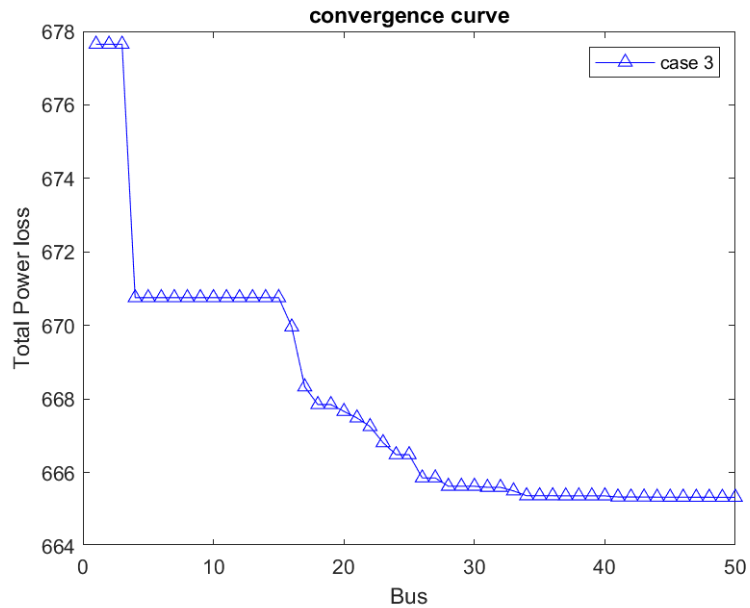

Fig 1.6

Fig. 1.5 and Fig. 1.6 shows the convergence curves of the AOA algorithm to reduce the total power loss using the DGs and capacitors for 34-bus test system. It is clear that, the AOA algorithm is able to reach the optimal solution with more accuracy and efficiency.

6.4.2. TVD minimization

6.4.2.1. 34-bus radial distribution system

Tables 1.11-1.15 show the optimal locations and sizes of DGs and the capacitors required to reduce the total voltage deviation (TVD) as an objective function for cases 1-5 for the 34-bus test system. Moreover, a comparison between the proposed procedure and other methods is presented.

Table 1.11 A comparison between the TVD minimization using the proposed procedure with other methods using only the DGs at unity power factor (case 1) for 34-bus test system

Items	Un-compensated (Case 0)	Compensated (Case 1)	
		Proposed procedure	
Optimal locations and sizes of DGs (kW)	-	26	1951.4
		32	1548.6
Total size	-	3500	
Total losses (kW)	221.752	82.9864	
TVD	**0.0483**	**.0017**	
Minimum bus voltage(p.u.)	0.9417 (#27)	0.9883 (#20)	
Maximum bus voltage(p.u.)	0.9941 (#2)	0.9977 (#2)	
Overall power factor	0.85	0.3678	

Table 1.1 presents the optimal solution for case 1 using the proposed procedure, when only active power from DGs is injected. It can be observed that, the initial TVD without DGs is reduced from .0483 to .0017 after placement of DGs. The optimal locations of DGs are at buses {26, 32} with total rating power 3500 kW. Moreover, the minimum and maximum voltage magnitudes are improved.

Table 1.12 A comparison between TVD minimization using the proposed procedure with other methods using only the DGs at 0.9 power factor (case 2) for 34-bus test system

Items	Un-compensated (Case 0)	Compensated (Case 2)	
		Proposed procedure	
Optimal locations and sizes of DGs (kW, kVAR)	-	**Locations**	**DG size (kW)**
		31	1500.1
		24	1999.9
Total size	-	-	3500
Total losses (kW)	221.752	24.32	
TVD	**0.0483**	. 000496	
Minimum bus voltage(p.u.)	0.9417 (#27)	0. 9932 (#19)	
Maximum bus voltage(p.u.)	0.9941 (#2)	1.0013 (#24)	
Overall power factor	0.85	. 6942	

Table 1.12 presents the optimal solution for case 2 using the proposed procedure, when active and reactive power from DGs are injected. It can be observed that, the initial TVD without compensation is reduced from .0483 to .000496 after placement of DGs. The optimal locations of DGs are at buses {31, 24} with total rating power 3500 kW.

Table 1.13 A comparison between TVD minimization using the proposed procedure with other methods using only the capacitors (case 3) for 34-bus test system

Items	**Un-compensated (Case 0)**	**Compensated (Case 3)**	
		Proposed procedure	
Optimal locations and sizes of capacitors (kVAR)	-	11	1200
		10	1199
		26	1200
Total size	-	3599.9	
Total losses (kW)	221.752	202.691	
TVD	**.0483**	**.0295**	
Minimum bus voltage(p.u.)	0.9417 (#27)	0.9532(#27)	
Maximum bus voltage(p.u.)	0.9941 (#2)	0.9956 (#2)	
Overall power factor	0.85	0.9879	

Table 1.13 presents the optimal solution for case 3 using the proposed procedure, when only reactive power from capacitors is injected. It is clear that, the initial TVD without compensation is reduced from .0483 to .0295 after placement of capacitors. The optimal locations of capacitors are at buses {11, 10,26} with total rating power 3599.9 kVAR.

Table 1.14 A comparison between the power loss minimization using the proposed procedure with other methods using DGs at unity power factor and capacitors (case 4) for 34-bus test system

Items	Un-compensated (Case 0)	Compensated (Case 4)	
		Proposed procedure	
Optimal locations and sizes of DGs (KW)	-	25	818.3
		25	1043.9
		11	1637.8
Total DGs size		3500	
Optimal locations and sizes of capacitors (KVAR)		19	821.6635
		6	555.721
Total capacitors size	-	1377.4	
Total losses (kW)	221.752	38.4743	
TVD	**.0483**	$\mathbf{7.7835 * 10^{-4}}$	
Minimum bus voltage(p.u.)	0.9417 (#27)	0.9914 (#20)	
Maximum bus voltage(p.u.)	0.9941 (#2)	1.0002 (#11)	
Overall power factor	0.85	0.6049	

Table 1.14 presents the optimal solution for case 4 using the proposed procedure, when active power from DGs is injected and reactive power is injected from capacitors . It can be observed that, the initial TVD without compensation is reduced from .0439 to $7.7835 * 10^{-4}$ after placement of DGs and capacitors. The optimal locations of DGs are at buses {25 25 11} with total rating power 3500 kW and the optimal locations of capacitors are at buses { 19, 6} with total power rating 1377.4 kVAR.

Table 1.15 A comparison between the power loss minimization using the proposed procedure with other methods using DGs at .9 power factor and capacitors (case 5) for 34-bus test system

Items	Base case	Case 5
		Proposed method
DG size (kW, kVAR) and location	-	1166.4, 564.8893 (#10), 993.1, 480.9892(#20), 1340.5, 649.2350 (#25)
Capacitor size (kVAR) and location	-	1059.4 (#17)
Total size of DGs (kW)	-	3500
Total size of capacitors (kVAR)	-	1059.4
f_1 [Loss (kW)]	221.752	9.2909
TVD	**.0483**	**2.3238e-04**
Min. voltage (p.u.)	0.9417 (#27)	0.9955(#30)
Overall p.f.	0.85	.9946

Table 1.15 presents the optimal solution for case 5 using the proposed procedure, when active power and reactive power from DGs are injected and reactive power is injected from capacitors . It can be observed that, the initial power loss without compensation is reduced from .0439 to 2.3238e-04 after placement of DGs and capacitors. The optimal locations of DGs are at buses {10, 20, 25} with total rating power 3500 kW and the optimal locations of capacitors are at buses { 17 } with total power rating 1059.4 kVAR.

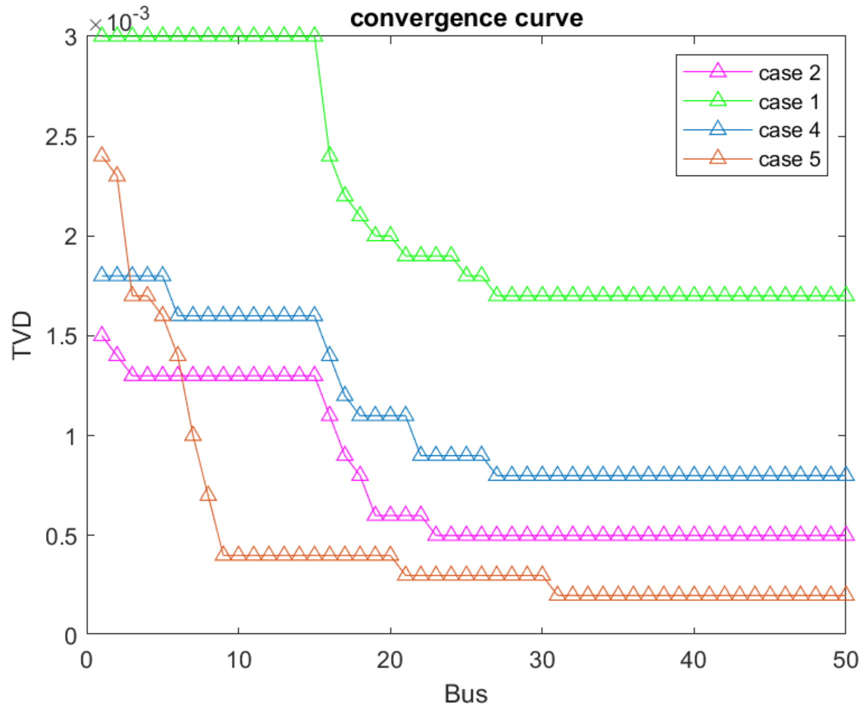
convergence curve
×10^-3
TVD
Bus
case 2
case 1
case 4
case 5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50

Fig. 1.7

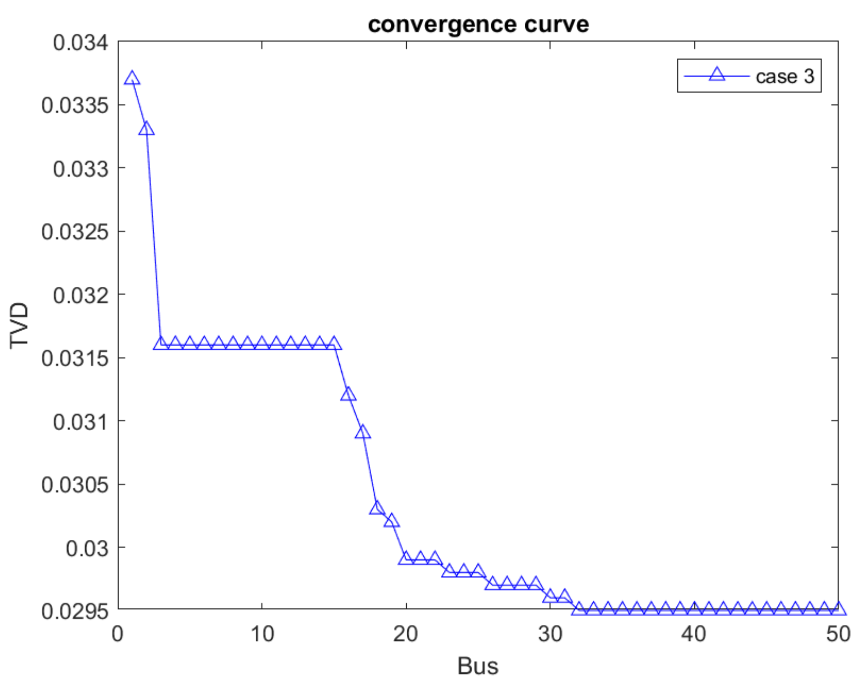
convergence curve
TVD
Bus
case 3
0.034
0.0335
0.033
0.0325
0.032
0.0315
0.031
0.0305
0.03
0.0295
0
10
20
30
40
50

Fig. 1.8

Fig. 1.7 and Fig. 1.8 shows the convergence curves of the AOA algorithm to reduce the TVD using the DGs and capacitors for 34-bus test system. It is clear that, the AOA algorithm is able to reach the optimal solution with more accuracy and efficiency.

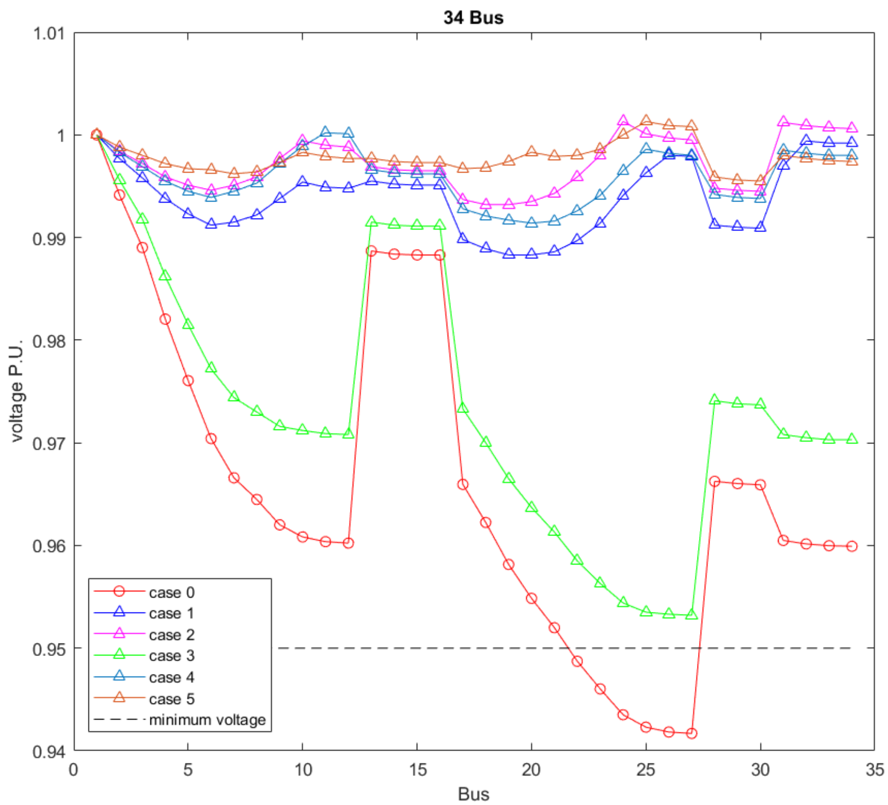

Fig. 1.9 Voltage profile at different cases for 34-bus test system

Fig. 1.9 shows the voltage profiles for cases 0-5, when the TVD minimization is considered as an objective function. The voltage profiles are improved at cases 1-5. Moreover, the minimum voltage limit is violated at buses starts from 22 to 27 in case 0.

6.4.2.2. EDN radial distribution system

Tables 1.16-1.20 show the optimal locations and sizes of DGs and the capacitors required to reduce the total voltage deviation (TVD) as an objective function for cases 1-5 for the EDN system. Moreover, a comparison between the proposed procedure and other methods is presented.

Table 1.16 Optimal locations and sizes of DGs at unity power factor to reduce TVD using the proposed method for EDN system (case 1)

Items	**Un-compensated (Case 0)**	**Compensated (Case 1)**	
Optimal locations and sizes of DGs (kW)	-	26	1999.9
		29	2000
Total size	-	3999.9	
Total losses (kW)	**805.73**	**572.0918**	
TVD	.0439	.0193	
Minimum bus voltage(p.u.)	0.9463 (#30)	0.9677 (#21)	
Maximum bus voltage(p.u.)	0.9854 (#2)	0.9874 (#2)	
Overall power factor	0.8457	0.7932	

Table 1.16 presents the optimal solution for case 1 using the proposed procedure, when only active power from DGs is injected. It can be observed that, the initial TVD without DGs is reduced from .0439 to .0193 after placement of DGs. The optimal locations of DGs are at buses {26 29} with total rating power 4000 kW.

Table 1.17 Optimal locations and sizes of DGs at 0.9 power factor using the proposed method for EDN system (case 2)

Items	Un-compensated (Case 0)	Compensated (Case 2)	
		Locations	DG size (kW)
Optimal locations and sizes of DGs (kW)	-	28	1999.7
		28	1999.3
Total size	-	-	3999
Total losses (kW)	**805.73**	**491.164**	
TVD	.0439	.0163	
Minimum bus voltage(p.u.)	0.9463 (#30)	0. 9703 (#20)	
Maximum bus voltage(p.u.)	0.9854 (#2)	0.9879 (#2)	
Overall power factor	0.8457	0.8335	

Table 1.17 presents the optimal solution for case 2 using the proposed procedure, when active and reactive power from DGs are injected. It can be observed that, the initial TVD without compensation is reduced from .0439 to .0163 after placement of DGs. The optimal locations of DGs are at buses {28, 28} with total rating power 3999 kW.

Table 1.18 Optimal locations and sizes of capacitors using the proposed method for EDN system (case 3)

Items	Un-compensated (Case 0)	Compensated (Case 3)	
Optimal locations and sizes of capacitors (kVAR)	-	25	441.5
		26	1198.3
		29	1194.8
		29	1165.4
Total size	-	4000	
Total losses (kW)	**805.73**	**712.8063**	
TVD	.0439	.0326	
Minimum bus voltage(p.u.)	0.9463 (#30)	0.9572 (#24)	
Maximum bus voltage(p.u.)	0.9854 (#2)	0.9865 (#2)	

Overall power factor	0.8457	0.9108

Table 1.18 presents the optimal solution for case 3 using the proposed procedure, when only reactive power from capacitors is injected. It is clear that, the initial power loss without compensation is reduced from .0439 to .0326 after placement of capacitors. The optimal locations of capacitors are at buses {25 26 29 29} with total rating power 4000 kVAR.

Table 1.19 A comparison between the TVD minimization using the proposed procedure with other methods using DGs at unity power factor and capacitors (case 4) for EDN system

Items	**Un-compensated (Case 0)**	**Compensated (Case 4)**	
		Proposed procedure	
Optimal locations and sizes of DGs (KW)	-	29	1143.6
		29	1221
		27	1635.3
Total DGs size		4000	
Optimal locations and sizes of capacitors (KVAR)		9	839.864
		27	467.45
Total capacitors size	-	1307	
Total losses (kW)	**805.73**	**531.637**	
TVD	.0439	.0177	
Minimum bus voltage(p.u.)	0.9463 (#30)	0.9686 (#21)	
Maximum bus voltage(p.u.)	0.9854 (#2)	0.9877 (#2)	
Overall power factor	0.8457	0.8204	

Table 1.19 presents the optimal solution for case 4 using the proposed procedure, when active power from DGs is injected and reactive power is injected from capacitors . It can

be observed that, the initial TVD without compensation is reduced from .0439 to .0177 after placement of DGs and capacitors. The optimal locations of DGs are at buses {29, 29, 27} with total rating power 4000 kW and the optimal locations of capacitors are at buses { 9, 27} with total power rating 1307 kVAR.

Table 1.20 A comparison between the power loss minimization using the proposed procedure with other methods using DGs at .9 power factor and capacitors (case 5) for EDN system

Items	Base case	Case 5
		Proposed method
DG size (kW, kVAR) and location	-	730.3, 353.722 (#23), 1026.6, 497.208 (#25), 2000 , 968.62 (#29)
Capacitor size (kVAR) and location	-	419.131 (#7) 382.583 (#24)
Total size of DGs (kW)	-	3756.9
Total size of capacitors (kVAR)	-	801.7141
f_1 [Loss (kW)]	**805.73**	**469.8317**
TVD	.0439	.017
Min. voltage (p.u.)	0.9463 (#30)	0.9701 (#20)
Overall p.f.	0.8457	.8508

Table 1.20 presents the optimal solution for case 5 using the proposed procedure, when active power and reactive power from DGs are injected and reactive power is injected from capacitors . It can be observed that, the initial TVD without compensation is reduced from .0439 to .017 after placement of DGs and capacitors. The optimal locations of DGs are at buses {23, 25, 29} with total rating power 3756.9 kW and the optimal locations of capacitors are at buses { 7, 24 } with total power rating 801.7 kVAR.

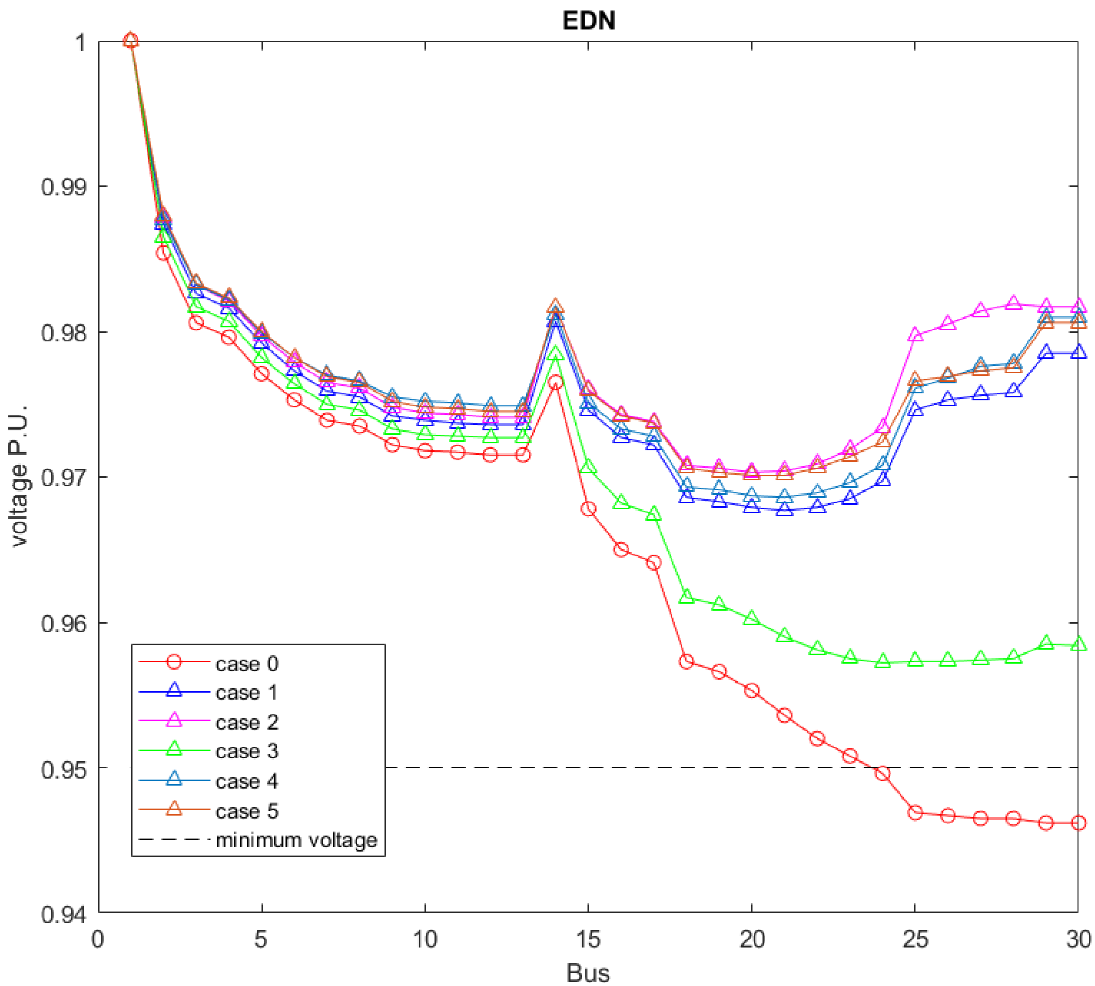

Fig. 1.10 Voltage profile for EDN system

Fig. 1.10 shows the voltage profiles for cases 0-5, when TVD minimization is considered as an objective function. The voltage profiles are improved at cases 1-5.

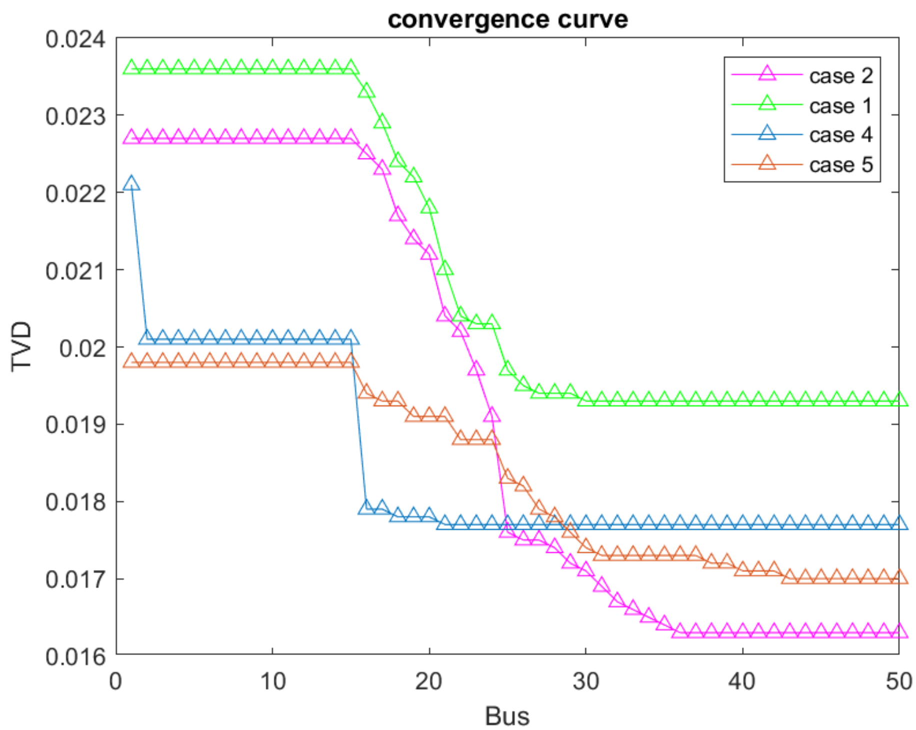

Fig 1.11

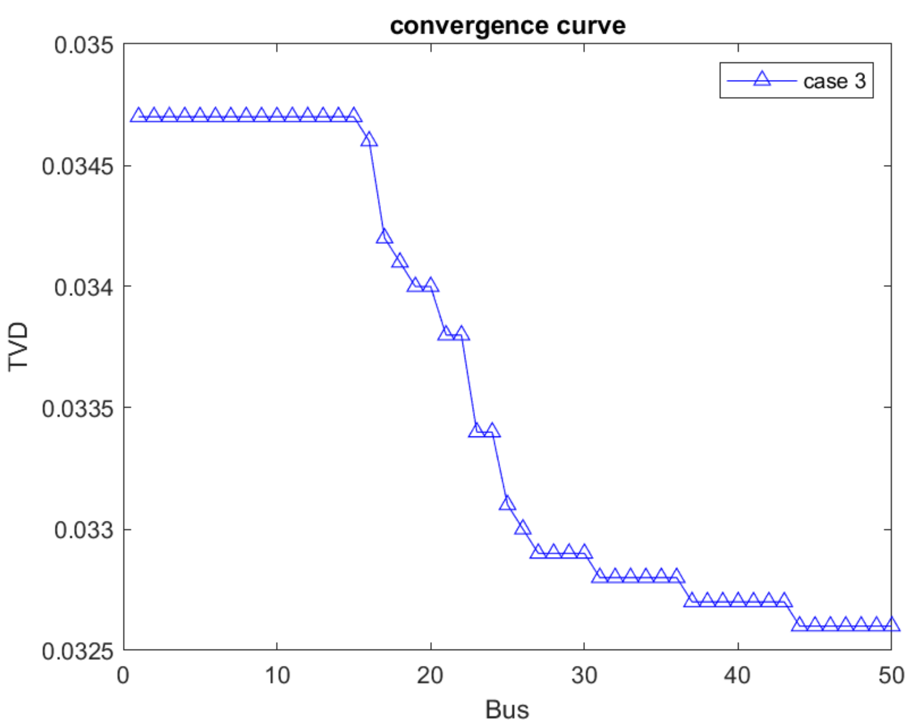

Fig 1.12

Fig. 1.11 and Fig. 1.12 shows the convergence curves of the AOA algorithm to reduce TVD using the DGs and capacitors for 34-bus test system. It is clear that, the AOA algorithm is able to reach the optimal solution with more accuracy and efficiency.

Appendix A

TEST SYSTEMS

A.1 34-Bus Distribution System

The single line diagram of 34-bus distribution system is shown in Fig. A.1. Tables A.1 and A.2 show the buses and lines data of 34-bus system, where the rated line voltage is 11 kV and rated MVA is 100.

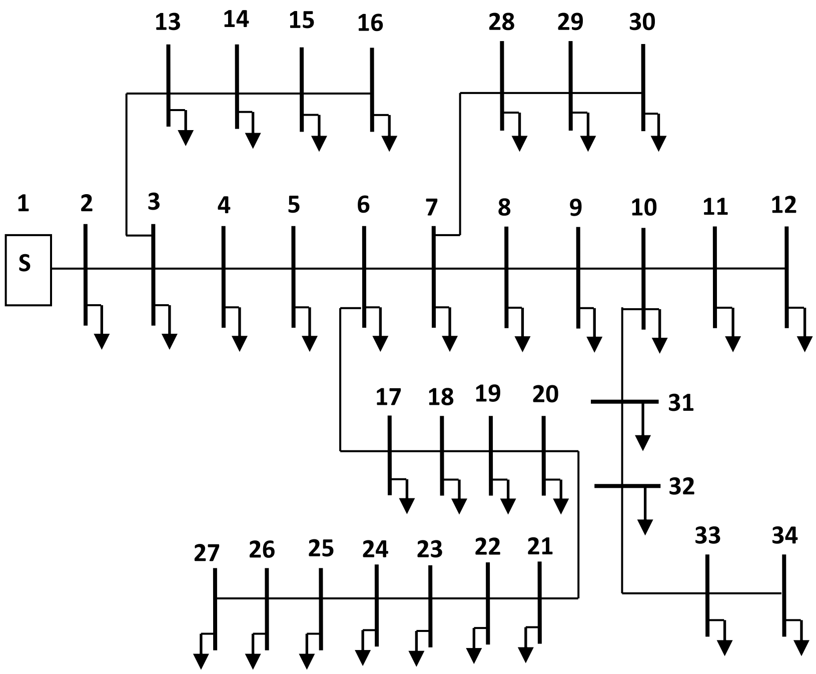

Fig. A.1 Single line diagram of 34-bus radial distribution system

Table A.1 Lines data for 34-bus distribution system

Line No.	Sending bus	Receiving bus	R (Ω)	X (Ω)
1	1	2	0.1170	0.0480
2	2	3	0.1073	0.0440
3	3	4	0.1645	0.0457
4	4	5	0.1495	0.0415
5	5	6	0.1495	0.0415
6	6	7	0.3144	0.0540
7	7	8	0.2096	0.0360
8	8	9	0.3144	0.0540
9	9	10	0.2096	0.0360
10	10	11	0.1310	0.0225
11	11	12	0.1048	0.0180
12	3	13	0.1572	0.0270
13	13	14	0.2096	0.0360
14	14	15	0.1048	0.0180
15	15	16	0.0524	0.0090
16	6	17	0.1794	0.0498
17	17	18	0.1645	0.0457
18	18	19	0.2079	0.0473
19	19	20	0.1890	0.0430
20	20	21	0.1890	0.0430
21	21	22	0.2620	0.0450
22	22	23	0.2620	0.0450
23	23	24	0.3144	0.0540
24	24	25	0.2096	0.0360
25	25	26	0.1310	0.0225
26	26	27	0.1048	0.0180

27	7	28	0.1572	0.0270
28	28	29	0.1572	0.0270
29	29	30	0.1572	0.0270
30	10	31	0.1572	0.0270
31	31	32	0.2096	0.0360
32	32	33	0.1572	0.0270
33	33	34	0.1048	0.0180

Table A.2 Bus data for 34-bus distribution system

Line No.	P (kW)	Q (kVAR)
1	0	0
2	230	142.5
3	0	0
4	230	142.5
5	230	142.5
6	0	0
7	0	0
8	230	142.5
9	230	142.5
10	0	0
11	230	142.5

12	137	84
13	72	45
14	72	45
15	72	45
16	13.5	7.5
17	230	142.5
18	230	142.5
19	230	142.5
20	230	142.5
21	230	142.5
22	230	142.5
23	230	142.5
24	230	142.5
25	230	142.5
26	230	142.5
27	137	85
28	75	48
29	75	48
30	75	48
31	57	34.5
32	57	34.5
33	57	34.5
34	57	34.5

A.2 East Delta Network (EDN) System

The single line diagram of EDN 30-bus distribution system is shown in Fig. A.2. Table A.3 shows the buses and lines data of EDN 30-bus system, where the rated line voltage is 11 kV and rated MVA is 100.

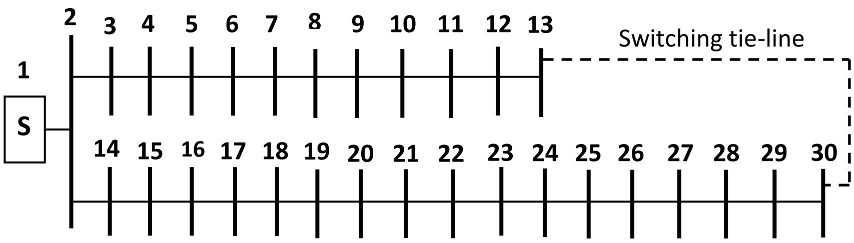

Fig. A.2 Single line diagram of the EDN distribution system

Table A.3 Buses and lines data for EDN distribution system

Line No.	Sending bus	Receiving bus	R (Ω)	X (Ω)	Load at Receiving bus	
					P (kW)	Q (kVAR)
1	1	2	0.05630	0.031500	2875	1814
2	2	3	0.07155	0.025974	1100	695
3	3	4	0.01855	0.006734	1058	669
4	4	5	0.05565	0.020202	899	568
5	5	6	0.05300	0.019240	770	486
6	6	7	0.05300	0.019240	668	423
7	7	8	0.02120	0.007696	598	378
8	8	9	0.10070	0.036556	546	345
9	9	10	0.04505	0.016354	380	240
10	10	11	0.03975	0.014430	210	132
11	11	12	0.11130	0.040404	94.586	59.368
12	12	13	0.01325	0.004810	34.423	21.518

13	2	14	0.06360	0.023088	1772	1118
14	14	15	0.07155	0.025974	1640	1035
15	15	16	0.02650	0.009620	1452	915
16	16	17	0.01060	0.003848	1434	904
17	17	18	0.09275	0.033670	1212	765
18	18	19	0.01060	0.003848	1086	685
19	19	20	0.02650	0.009620	953	602
20	20	21	0.04505	0.016354	827	521
21	21	22	0.05300	0.019240	716	452
22	22	23	0.05300	0.019240	550	347
23	23	24	0.0663	0.0240	434	273
24	24	25	0.2253	0.0818	346	218
25	25	26	0.0265	0.0096	316	199
26	26	27	0.0265	0.0096	184	116
27	27	28	0.0133	0.0048	139	87.911
28	28	29	0.1723	0.0625	113	71.734
29	29	30	0.0080	0.0029	34.25	21.734

Appendix B

BACKWARD/FORWARD SWEEP (BFS) ALGORITHM

The backward/forward sweep (BFS) algorithm is one of the most common ways used for load flow distribution system because it is simple, fast and robust convergence and low memory requirement. The BFS algorithm involves mainly an iterative three basic steps based on Kirchhoff's current law (KCL) and Kirchhoff's voltage law (KVL). The three steps are named as the nodal current calculation, the backward sweep and the forward sweep and they are repeated until the convergence is achieved. In the nodal current calculation, all the current injection at different buses is determined. In the backward sweep, the section currents and powers are calculated starting from the last node and proceeds towards substation node. In the forward sweep, the voltage at each node is calculated starting from the substation node and proceeds towards last node. The input data required for this algorithm are the numbering of sending and receiving nodes, the branch data represented by resistance and reactance and the active and reactive powers at each node. The BFS utilizes a simple and flexible radial distribution system numbering scheme in order to numbering each branch in the feeder, lateral and sub-lateral [24].

The BFS algorithm can be applied to find the load flow results using the following steps:

***Step 1*: Initialization**

Insert the following:

- The distribution system line and load data.
- The base power and base voltage.
- Calculate the base impedance.

- Calculate the per unit values of line and load data.
- Take the voltage for all buses flat voltage (1 p.u.).
- Set convergence tolerance Є=0.0001 and $\Delta V_{max} = 0$.

***Step 2*: Radial distribution system numbering scheme**

The numbering scheme aims to give a number to each section in the distribution system, where a section is part of a feeder, lateral or sub-lateral that connects two buses in the distribution system. The total number of sections (N_{Sec}^{Total}) of a distribution system can be calculated as:

$$N_{Sec}^{Total} = N_{bus}^{Total} - 1 \tag{B.1}$$

where, N_{bus}^{Total} is the total number of buses. Each section will carry a number which is one less than its receiving end bus number, e.g., the number of section that connects the sending end p and the receiving end q in Fig. 5.1 can be calculated as:

$$N_{\left(\frac{Sec}{p-q}\right)} = N_{\left(\frac{bus}{q}\right)} - 1 \tag{B.2}$$

where, $N_{(Sec\ /p\text{-}q)}$ is the section number between buses p and q, $N_{(bus\ /q)}$ is the number of bus q.

Now, the radial distribution system numbering scheme should be applied on the distribution system to give a number to each section in the system.

***Step 3*: Nodal current calculation**

At iteration k, the nodal current injection at node i due to loads and any other shunt elements can be calculated as:

$$I_i^{(k)} = \left(\frac{S_i}{V_i^{(k-1)}}\right)^* - (Y_i)\left(V_i^{(k-1)}\right) \tag{B.3}$$

where, $I_i^{(k)}$ is the current injection at node i, S_i is the specified power injection at node i, $V_i^{(k-1)}$ is the voltage at node i at iteration $k-1$, Y_i is the sum of all shunt elements at node i.

Step 4: Backward sweep

At iteration k, start from the branches at the end nodes and moving towards the branches connected to the substation. Hence, all branch currents can be calculated by applying the KCL and then the powers through these branches can be determined. For the branch L, the current and power flows can be calculated as:

$$I_L^{(k)} = -I_j^{(k)} - \sum_{m=1}^{M} \left(\frac{S_m}{V_j^{(k)}} \right)^* \tag{B.4}$$

$$S_L^{(k)} = \left(V_j^k + Z_L * I_L^k \right) \left(I_L^k \right)^* \tag{B.5}$$

where, $I_L^{(k)}$ is the current flow in branch L at iteration k, $I_j^{(k)}$ is the current injected due to shunt elements at bus j, M is the number of branches connected to bus j, S_m is the complex power at the sending end of branch m, $V_j^{(k)}$ is the voltage at bus j, $S_L^{(k)}$ is the power flow in branch L and Z_L is the impedance of branch L.

Step 5: Forward sweep

At iteration k, the nodal voltages are updated in a forward sweep starting from the branches in the first section toward those in the last by applying the KVL. For a branch L connected sending end p and receiving end q, the voltage at receiving end at iteration k can be calculated as:

$$V_q^{(k)} = V_p^{(k)} - Z_L * I_L^{(k)} \tag{B.6}$$

where, $V_p^{(k)}$ and $V_q^{(k)}$ are the voltages at sending and receiving ends, respectively.

Step 6: Check the voltage mismatches

After the previous steps have been computed, the voltage mismatches for all nodes are calculated, e.g., the voltage mismatch at bus *i* at iteration *k* can be calculated as:

$$\Delta V_i^{(k)} = \left| \left| V_i^{(k)} \right| - \left| V_i^{(k-1)} \right| \right| \tag{B.7}$$

After calculating the voltage mismatches, check the convergence of the voltage as:

- If $\Delta V_i^{(k)} > \Delta V_{max}$, then make $\Delta V_{max} = \Delta V_i^{(k)}$.
- If $\Delta V_{max} \leq \epsilon$, go to step 8, otherwise increment the iteration number and go to step 3.

<u>Step 7</u>: Check stopping criterion

The program will be terminated when the maximum iteration is reached or the convergence from the voltage mismatches is verified.

<u>Step 8</u>: Power loss calculation

After computing the node voltages and branch currents using the BFS algorithm, the total active and reactive power losses in the distribution system are calculated from Equations (4.3) and (4.4).

The steps of the BFS algorithm to find the radial distribution system load flow are shown in Fig. B.1.

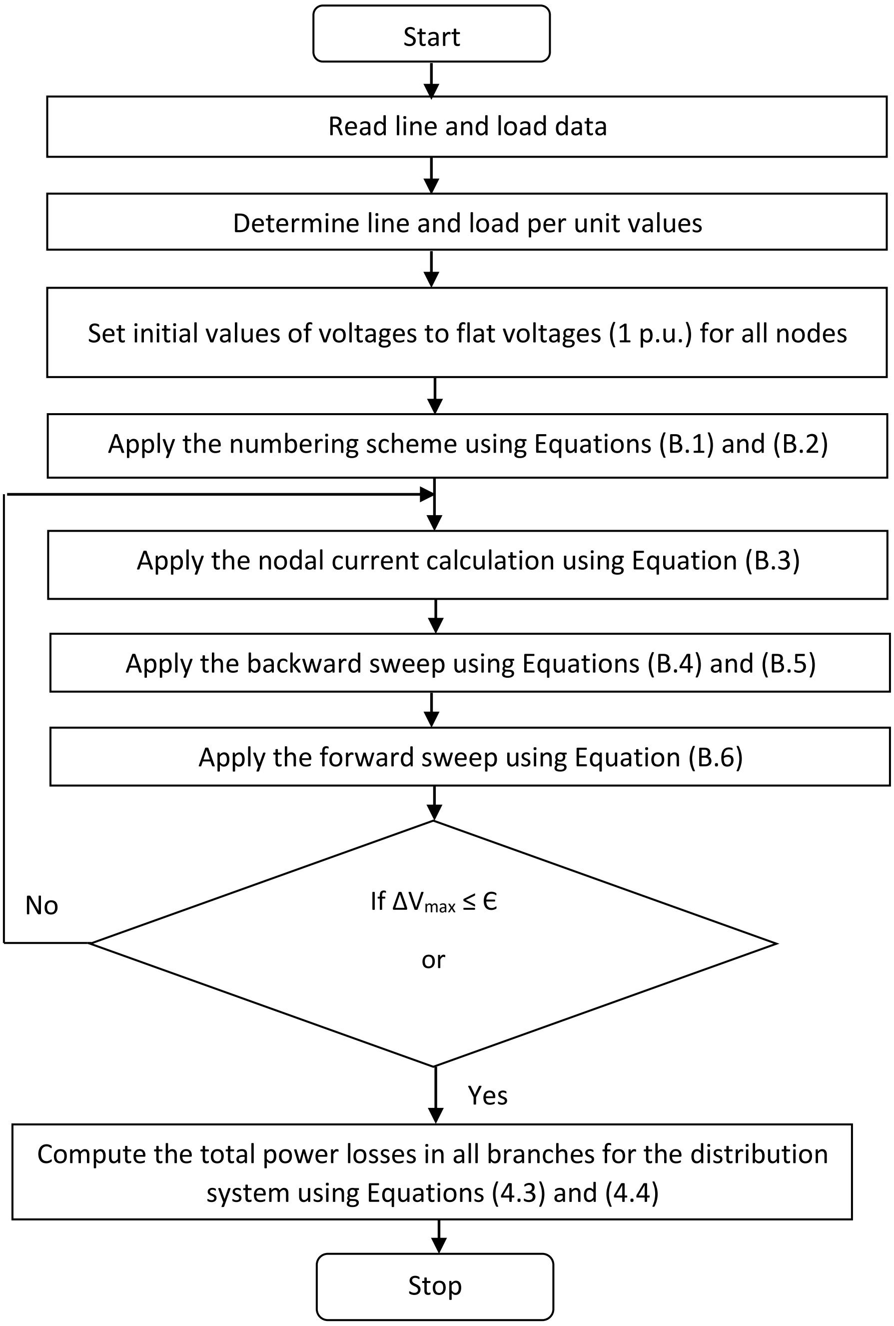

Fig. B.1 Flow chart of backward/forward sweep load flow