Appendices

Contents

A System Data

This section details the bus and line data used in the study.

A.1 5-Bus Test System

The total active power demand of this distribution system in Table 1 is 400 kW. Table 2 compares the load flow results of the implemented BFS with published results. Running BFS on the 33-Bus yields solutions consistent with the published results in Bouchekara et al., 2020.

Table 1: Bus and Line Data of a 5-Bus RDS

Line No.	Snd. Bus	Rcv. Bus (Bus No.)	Load at Rcv. Bus		Line Impedance		Imax (Amps)
			P (kW)	Q (kVAr)	R (ohms)	X (ohms)	
	S/S	1	0	0	0	0	N/A
1	1	2	100	60	0.0922	0.0470	400
2	2	3	90	40	0.4930	0.2510	400
3	3	4	120	80	0.3661	0.1864	400
4	2	5	90	40	0.1640	0.1564	400
Base MVA: 100 MVA				Base Voltage: 12.66 kV			

Table 2: Summary of IEEE 33-Bus Load Flow Analysis Results

IEEE 33-Bus Test System	**BFS**	**Bouchekara et al., 2020**
Tot. Active Power Loss (kW)	202.6771	202.6771
Tot. Reactive Power Loss (kVAr)	135.1410	135.1410
Minimum Voltage (pu)	0.913	0.913
Min. Voltage Bus Location	Bus 18	Bus 18

A.2 IEEE 33-Bus System

The total demand is 3.715 MW active and 2.3 MVAr reactive power. Table 3 summarizes the bus and line data.

B Development of Load Profiles

To model load profiles consistent with the 33-bus system's distribution transformer level demand, 300 houses were divided into 32 buses of 9 house each. This yielded an annual hourly load demand for each of the 32 buses. These load profiles are used for multi-level, daily, and seasonal load analyses.

B.1 Peak Load Profile

For the comparison with published results, Table 3 peak loads were used. The peak load profile used in test cases is detailed in Table 4. The line data used here is the same with Table 3.

Table 3: Bus and Line Data of the IEEE33-Bus RDS

Line No.	**Snd. Bus**	**Rcv. Bus (Bus no.)**	**Load at Rcv. Bus**			**Line Impedance**		**Imax**
			P (kW)	**Q (kVAr)**	**Pf**	**R (ohms)**	**X (ohms)**	
	S/S	1	0	0	0	0	0	N/A
1	1	2	100	60	0.8575	0.0922	0.0470	400
2	2	3	90	40	0.9138	0.4930	0.2510	400
3	3	4	120	80	0.8321	0.3661	0.1864	400
4	4	5	60	30	0.8944	0.3811	0.1941	400
5	5	6	60	20	0.9487	0.8190	0.7070	400
6	6	7	200	100	0.8944	0.1872	0.6188	300
7	7	8	200	100	0.8944	1.7117	1.2357	300
8	8	9	60	20	0.9487	1.0299	0.7400	200
9	9	10	60	20	0.9487	1.0440	0.7400	200
10	10	11	45	30	0.8321	0.1967	0.0651	200
11	11	12	60	35	0.8638	0.3744	0.1237	200
12	12	13	60	35	0.8638	1.4680	1.1549	200
13	13	14	120	80	0.8321	0.5416	0.7129	200
14	14	15	60	10	0.9864	0.5909	0.5260	200
15	15	16	60	20	0.9487	0.7462	0.5449	200
16	16	17	60	20	0.9487	1.2889	1.7210	200
17	17	18	90	40	0.9138	0.7320	0.5739	200
18	2	19	90	40	0.9138	0.1640	0.1564	200
19	19	20	90	40	0.9138	1.5042	1.3555	200
20	20	21	90	40	0.9138	0.4095	0.4784	200
21	21	22	90	40	0.9138	0.7089	0.9373	200
22	3	23	90	50	0.8742	0.4512	0.3084	200
23	23	24	420	200	0.9029	0.8980	0.7091	200
24	24	25	420	200	0.9029	0.8959	0.7010	200
25	6	26	60	25	0.9231	0.2031	0.1034	300
26	26	27	60	25	0.9231	0.2842	0.1447	300
27	27	28	60	20	0.9487	1.0589	0.9338	300
28	28	29	120	70	0.8638	0.8043	0.7006	200
29	29	30	200	600	0.3162	0.5074	0.2585	200
30	30	31	150	70	0.9062	0.9745	0.9629	200
31	31	32	210	100	0.9029	0.3105	0.3619	200
32	32	33	60	40	0.8321	0.3411	0.5302	200
Base MVA: 100 MVA				Base Voltage: 12.66 kV				

Table 4: Peak Load Profile Bus Data for Test Case 2

Bus	**P (kW)**	**Q (kVAr)**
1	0	0
2	96.4926	57.8956
3	86.8396	38.5954
4	128.6932	85.7955
5	72.0976	36.0488
6	91.2525	30.4175
7	90.7906	45.3953
8	82.3049	41.1524
9	34.2916	11.4305
10	76.0445	25.3482
11	87.0537	58.0358
12	80.9403	47.2151
13	131.4014	76.6508
14	73.3362	48.8908
15	131.4854	21.9142
16	97.0594	32.3531
17	127.7695	42.5898
18	88.2	39.2
19	84.7486	37.666
20	67.714	30.0951
21	60.2822	26.7921
22	121.2403	53.8846
23	77.556	43.0867
24	184.7052	87.9548
25	82.6492	39.3567
26	75.2971	31.3738
27	60.1898	25.0791
28	94.2966	31.4322
29	93.4653	54.5214
30	155.4479	466.3438
31	110.6761	51.6489
32	77.2579	36.7895
33	78.421	52.2806

B.2 Variable Load Profile

B.2.1 Multi-Level Load Demand (3 Hours)

The multi-level profile captures large variations that may not be reflected in daily or seasonal profiles. Fig. 1 illustrates extracting the demand levels directly from the load datasets rather than multiplying a factor to a peak profile, as typically done in existing literature. Table 5 tabulates the corresponding demands for each hour.

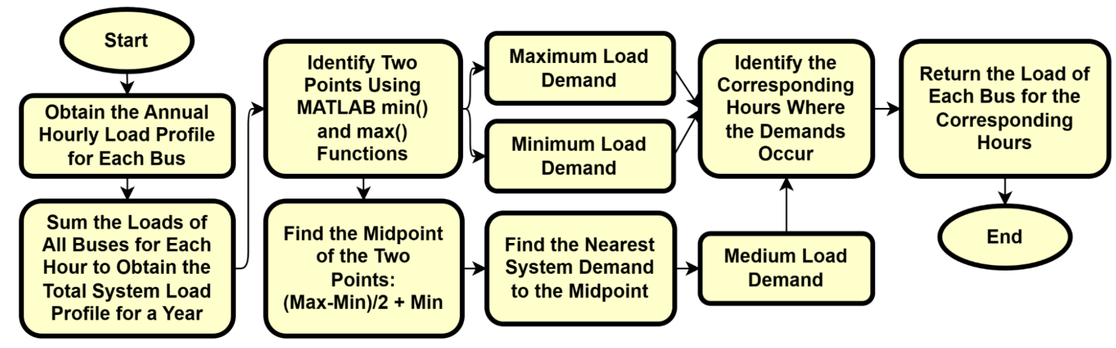

Figure 1: 3-Hour Load Profile Development Flowchart.

B.2.2 Daily Load Demand (24 Hours)

The daily load profile consists of 24 hours of load data for the system. To determine this load profile, we first assumed that demand on weekdays and weekends did not differ significantly. Figure 2 illustrates the process of extracting a representative daily load profile. The detailed load of each bus for 24 hours could be accessed through the supplementary materials titled Appendix_Daily_Load_P_Data.xlsx and Appendix_Daily_Load_Q_Data.xlsx.

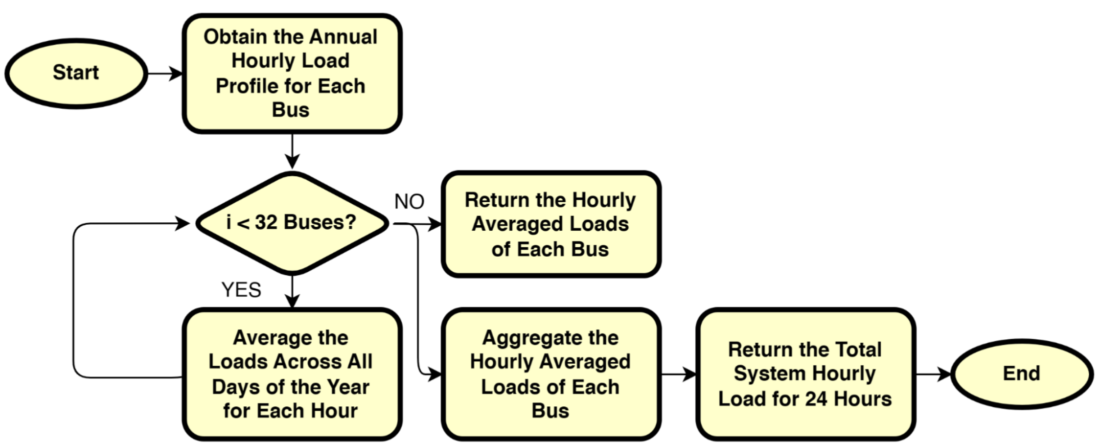

Figure 2: 24-Hour Load Profile Development Flowchart.

Table 5: Load Demand of 33 Buses for 3 Hours

	P (kW)			**Q (kVAr)**		
Bus	**Hour 1**	**Hour 2**	**Hour 3**	**Hour 1**	**Hour 2**	**Hour 3**
1	0	0	0	0	0	0
2	8.4858	64.4516	96.4926	5.0915	38.6709	57.8956
3	8.935	48.282	86.8396	3.9711	21.4587	38.5954
4	7.8811	41.2028	128.6932	5.2541	27.4685	85.7955
5	8.5614	57.998	72.0976	4.2807	28.999	36.0488
6	7.6754	57.9392	91.2525	2.5585	19.3131	30.4175
7	8.7167	44.3225	90.7906	4.3584	22.1613	45.3953
8	13.0079	60.0554	82.3049	6.5039	30.0277	41.1524
9	15.4558	33.7835	34.2916	5.1519	11.2612	11.4305
10	18.101	42.1559	76.0445	6.0337	14.052	25.3482
11	9.1366	39.2378	87.0537	6.0911	26.1585	58.0358
12	13.285	75.9815	80.9403	7.7496	44.3225	47.2151
13	11.828	47.6354	131.4014	6.8997	27.7873	76.6508
14	11.131	45.1665	73.3362	7.4207	30.111	48.8908
15	10.1065	35.5092	131.4854	1.6844	5.9182	21.9142
16	12.0086	88.876	97.0594	4.0029	29.6253	32.3531
17	10.8371	39.1664	127.7695	3.6124	13.0555	42.5898
18	16.9128	62.0792	88.2	7.5168	27.5908	39.2
19	10.4592	51.851	84.7486	4.6485	23.0449	37.666
20	7.1757	49.4661	67.714	3.1892	21.9849	30.0951
21	13.1003	48.853	60.2822	5.8223	21.7125	26.7921
22	9.4095	62.243	121.2403	4.182	27.6636	53.8846
23	11.6601	69.3096	77.556	6.4778	38.5053	43.0867
24	14.0828	44.9355	184.7052	6.7061	21.3979	87.9548
25	9.3423	66.1521	82.6492	4.4487	31.501	39.3567
26	7.2933	62.2094	75.2971	3.0389	25.9206	31.3738
27	9.2206	49.0966	60.1898	3.8419	20.4569	25.0791
28	10.1653	42.1266	94.2966	3.3884	14.0422	31.4322
29	11.8322	39.6073	93.4653	6.9021	23.1042	54.5214
30	17.341	55.6383	155.4479	52.0231	166.9149	466.3438
31	7.9777	32.4651	110.6761	3.7229	15.1504	51.6489
32	8.2338	67.3487	77.2579	3.9209	32.0708	36.7895
33	12.2563	50.8349	78.421	8.1709	33.8899	52.2806

B.2.3 Seasonal Load Demand (96 Hours)

We condensed four seasons into a 96-hour load profile, where each season is represented in a 24-hour period. Figure 3 provides an illustration of how the seasonal load profiles are developed. The detailed load of each bus for 96 hours could be accessed through the supplementary materials titled Appendix_Seasonal_Load_P_Data.xlsx and Appendix_Seasonal_Load_Q_Data.xlsx.

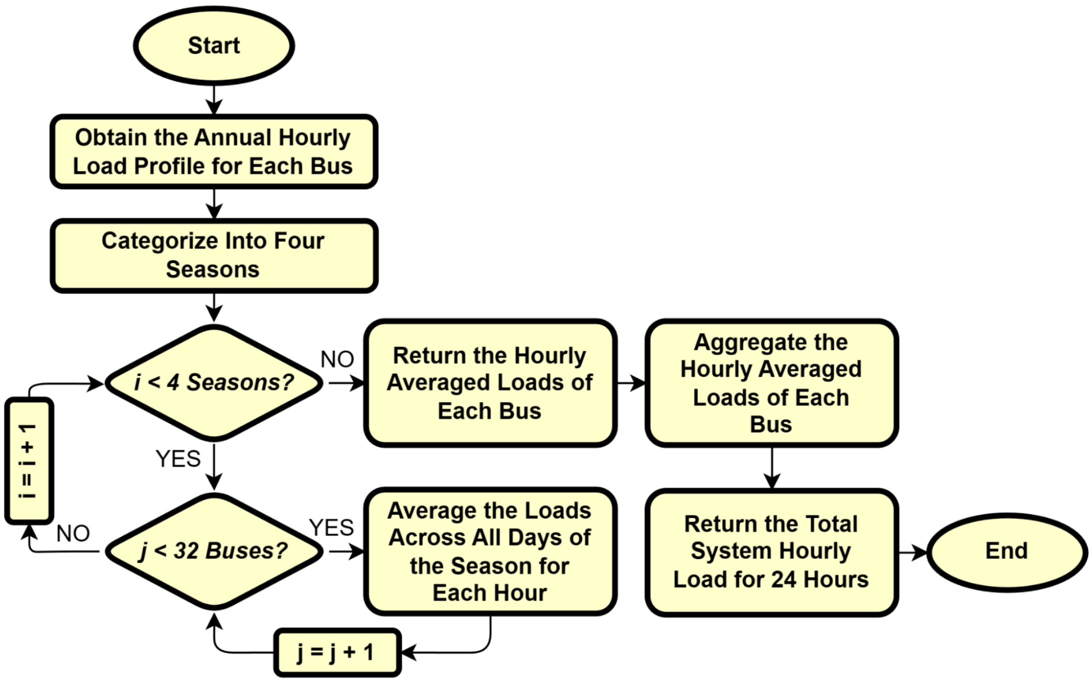

Figure 3: 96-Hour Load Profile Development Flowchart.

C Results Data

This section details the bus and line data used in the study.

C.1 Comparison of Published Results For Single DG Integration

Table 6 presents the optimal allocation of a DG with the corresponding power losses from studies conducted until 2016. Results indicate that both WOA and E-WOA are effective optimizers for this problem.

C.2 Optimization Algorithm

C.2.1 Whale Optimization Algorithm (WOA)

Fig. 4 presents the optimal flowchart of WOA including the modifications implemented for solving the mixed-integer ODGA problem.

Table 6: Optimization Results for Single DG in IEEE 33-Bus System at Unity Power Factor

Year	Algorithm	DG Location	DG Size (kW)	Power Loss (kW)
Base		-	-	210.988
2016[a]	BFOA	6	2200.000	113.140
2016[b]	HSA-PABC	6	2598.000	111.030
2017[c]	GWO	6	2761.820	111.420
2018[d]	GA	6	2600.000	111.030
2018[e]	DA	6	2590.200	111.034
2021[f]	MRFO	6	2590.217	111.027
2021[g]	PFA	6	2590.264	111.030
2022[h]	HBA	30	1542.000	125.000
Present	**WOA**	**6**	**2590.217**	**111.019**
Present	**E-WOA**	**6**	**2590.217**	**111.019**

[a] Devabalaji et al., 2016.

[b] Muthukumar et al., 2016.

[c] El-Sayed et al., 2017.

[d] Kashyap et al., 2018.

[e] Suresh et al., 2018.

[f] Hemeida et al., 2021.

[g] Janamala, 2021.

[h] Khan, 2022.

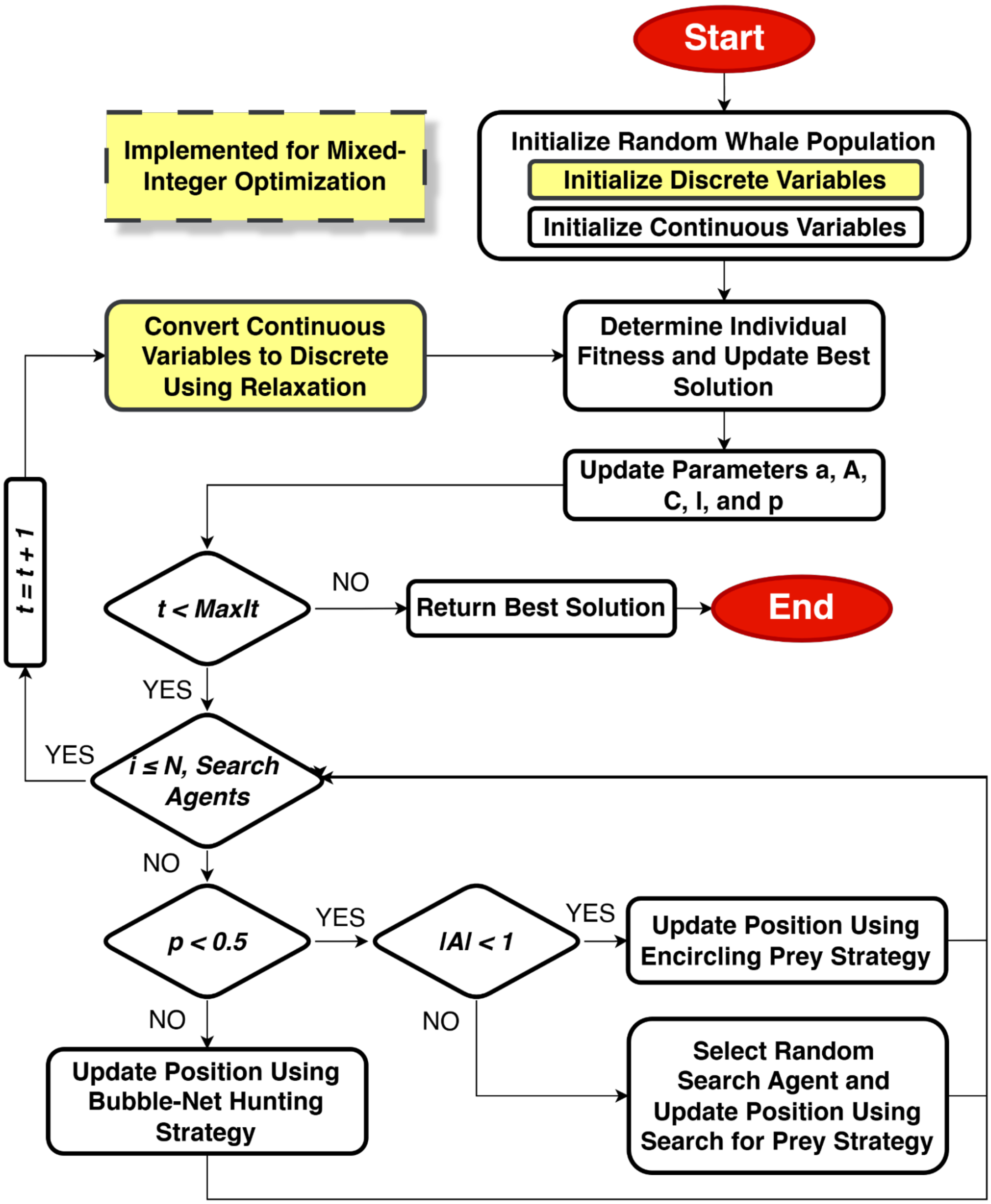

Figure 4: Whale Optimization Algorithm Flowchart.

C.3 Convergence Curves

The following figures illustrate the convergence curves of WOA and E-WOA for 100 runs as well as the comparison of their best convergence curves.

C.3.1 Case 1 Comparison

Fig. 5 presents the comparison of the best convergence curve of each algorithm for Case 1.

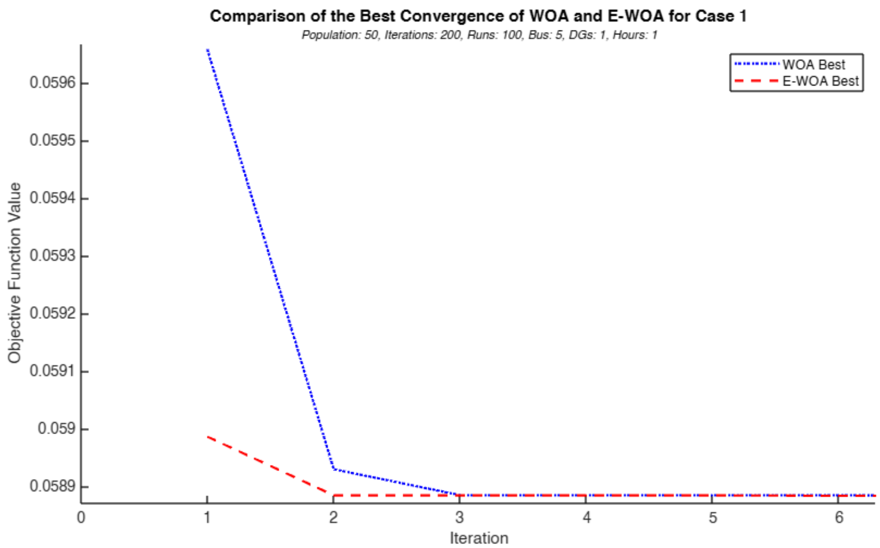

Figure 5: Comparison of Best Convergence Curves for Case 1.

C.3.2 Case 2 Comparison

Fig. 6 presents the comparison of the best convergence curve of each algorithm for Case 2.

C.3.3 Case 3 Comparison

Fig. 7 presents the comparison of the best convergence curve of each algorithm for Case 3.

C.3.4 Case 5 Comparison

Fig. 8 presents the comparison of the best convergence curve of each algorithm for Case 5. Since E-WOA failed to find any feasible solutions in 100 runs, only WOA's convergence curve is shown.

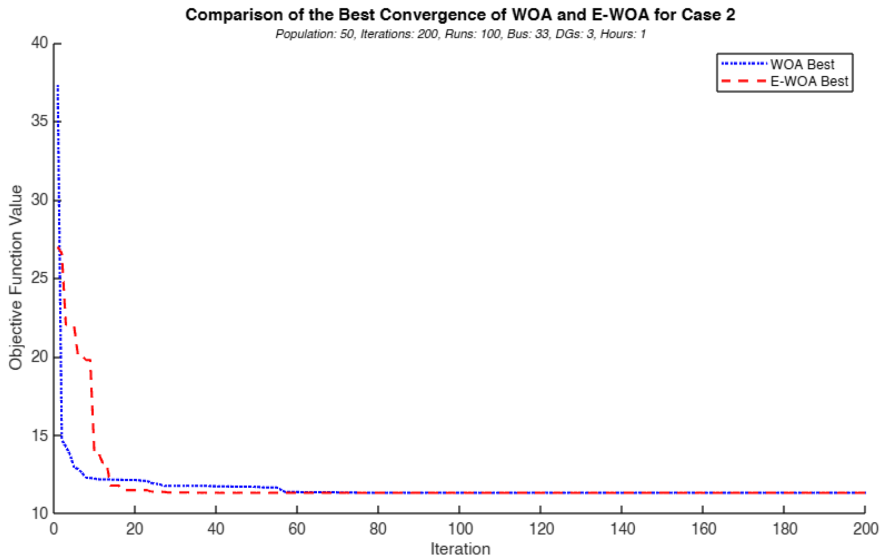

Figure 6: Comparison of Best Convergence Curves for Case 2.

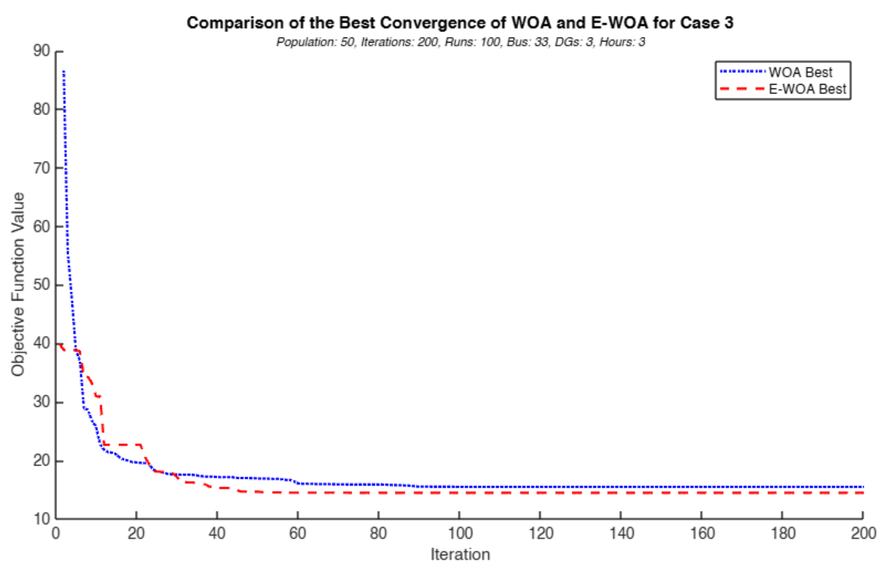

Figure 7: Comparison of Best Convergence Curves for Case 3.

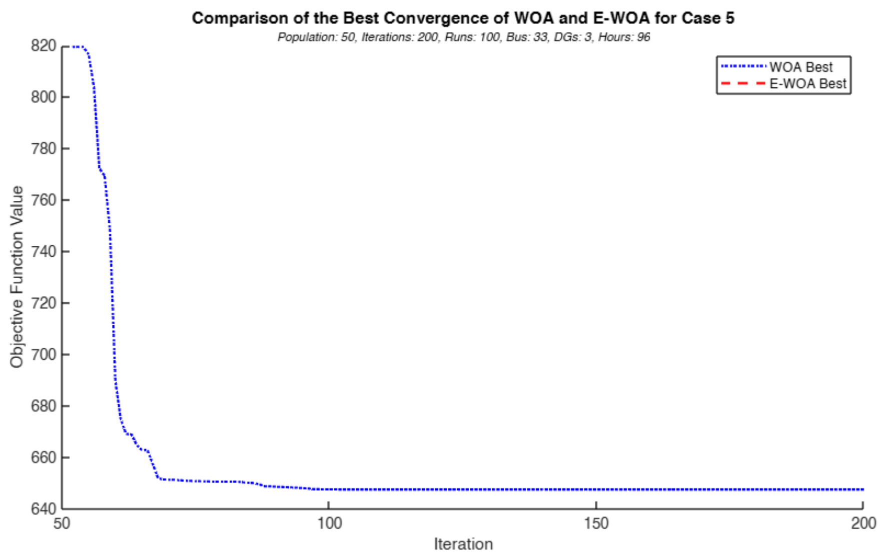

Figure 8: Comparison of Best Convergence Curves for Case 5.