Chapter 4

Result And Discussion

4.1 Performance Analysis

- **SIMULATION OF THE SYSTEM**

The IEEE 6 bus system model has been examined for power flow using the PSAT 2.1.8 toolkit. The model has previously been run using this IEEE 30,57 bus architecture and is already accessible in the toolbox.

POWER FLOW REPORT

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P S A T 2.1.8

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File:  F:\psat\tests\d_014.mdl


NETWORK STATISTICS

Buses:                        14
Lines:                        16
Transformers:                 4
Generators:                   5
Loads:                        11

SOLUTION STATISTICS

Number of Iterations:         4
Maximum P mismatch [p.u.]     0
Maximum Q mismatch [p.u.]     0
Power rate [MVA]            100
```

POWER FLOW RESULTS						
Bus	V	phase	P gen	Q gen	P load	Qload
	[p.u.]	[rad]	[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 01	1.06	0	3.5205	-0.27899	0	0
Bus 02	1.045	-0.13555	0.4	0.95134	0.3038	0.1778
Bus 03	1.01	-0.3316	0	0.59796	1.3188	0.266
Bus 04	0.99772	-0.26346	0	0	0.6692	0.056

Bus 05	1.0024	-0.22748	0	0	0.1064	0.0224
Bus 06	1.07	-0.37954	0	0.44264	0.1568	0.105
Bus 07	1.0347	-0.3539	0	0	0	0
Bus 08	1.09	-0.3539	0	0.34242	0	0
Bus 09	1.0111	-0.40186	0	0	0.413	0.2324
Bus 10	1.0105	-0.40493	0	0	0.126	0.0812
Bus 11	1.0346	-0.39504	0	0	0.049	0.0252
Bus 12	1.0461	-0.40144	0	0	0.0854	0.0224
Bus 13	1.0362	-0.40319	0	0	0.189	0.0812
Bus 14	0.99568	-0.42852	0	0	0.2086	0.07

LINE FLOWS

From Bus	To Bus	Line	P Flow	Q Flow	P Loss	QLoss
			[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 02	Bus 05	1	0.58278	0.07227	0.01814	0.01975
Bus 06	Bus 12	2	0.11726	0.04464	0.00169	0.00352
Bus 12	Bus 13	3	0.03017	0.01873	0.00025	0.00023
Bus 06	Bus 13	4	0.27313	0.14163	0.00547	0.01077
Bus 06	Bus 11	5	0.14449	0.12199	0.00297	0.00621
Bus 11	Bus 10	6	0.09253	0.09057	0.00129	0.00301
Bus 09	Bus 10	7	0.0348	-0.00626	4e-05	0.0001
Bus 09	Bus 14	8	0.104	0.01006	0.00136	0.00289
Bus 14	Bus 13	9	-0.10596	-0.06283	0.00262	0.00533
Bus 07	Bus 09	10	0.45586	0.23268	0	0.02692
Bus 01	Bus 02	11	2.415	-0.38021	0.10271	0.2551
Bus 03	Bus 02	12	-1.0003	0.13866	0.04729	0.15297
Bus 03	Bus 04	13	-0.31849	0.1933	0.00959	-.0104

Bus 01	Bus 05	14	1.1056	0.10122	0.05957	0.19356
Bus 05	Bus 04	15	0.81253	-0.13835	0.009	0.0156
Bus 02	Bus 04	16	0.77808	0.05165	0.03249	0.05955
Bus 04	Bus 09	17	0.09598	0.03594	5e-05	0.00551
Bus 05	Bus 06	18	0.69168	0.07613	0	0.1055
Bus 04	Bus 07	19	0.45586	-0.05009	0	0.04226
Bus 08	Bus 07	20	0	0.34242	0	0.01738

LINE FLOWS

From Bus	To Bus	Line	P Flow	Q Flow	P Loss	QLoss
			[p.u.]	[p.u.]	[p.u.]	[p.u.]
Bus 05	Bus 02	1	-0.56464	-0.05252	0.01814	0.01975
Bus 12	Bus 06	2	-0.11557	-0.04113	0.00169	0.00352
Bus 13	Bus 12	3	-0.02991	-0.0185	0.00025	0.00023
Bus 13	Bus 06	4	-0.26766	-0.13086	0.00547	0.01077
Bus 11	Bus 06	5	-0.14153	-0.11577	0.00297	0.00621
Bus 10	Bus 11	6	-0.09124	-0.08757	0.00129	0.00301
Bus 10	Bus 09	7	-0.03476	0.00637	4e-05	0.0001
Bus 14	Bus 09	8	-0.10264	-0.00717	0.00136	0.00289
Bus 13	Bus 14	9	0.10857	0.06816	0.00262	0.00533
Bus 09	Bus 07	10	-0.45586	-0.20577	0	0.02692
Bus 02	Bus 01	11	-2.3123	0.63531	0.10271	0.2551
Bus 02	Bus 03	12	1.0476	0.01431	0.04729	0.15297
Bus 04	Bus 03	13	0.32807	-0.2037	0.00959	-0.0104

Bus 05	Bus 01	14	-1.046	0.09234	0.05957	0.19356
Bus 04	Bus 05	15	-0.80353	0.15395	0.009	0.0156
Bus 04	Bus 02	16	-0.74559	0.00791	0.03249	0.05955
Bus 09	Bus 04	17	-0.09593	-0.03043	5e-05	0.00551
Bus 06	Bus 05	18	-0.69168	0.02938	0	0.1055
Bus 07	Bus 04	19	-0.45586	0.09235	0	0.04226
Bus 07	Bus 08	20	0	-0.32503	0	0.01738

GLOBAL SUMMARY REPORT

TOTAL GENERATION

REAL POWER [p.u.]	3.9205
REACTIVE POWER [p.u.]	2.0554
TOTAL LOAD	
REAL POWER [p.u.]	3.626
REACTIVE POWER [p.u.]	1.1396
TOTAL LOSSES	
REAL POWER [p.u.]	0.29452
REACTIVE POWER [p.u.]	0.91576

This section explains the experimental results and discussion of the hybrid KGMO-CSA method-based optimal allocation of FACTS devices. This hybrid KGMO-CSA method is simulated using the MATLAB R2020a software, which runs on a Windows 10 operating system with an Intel Core i5 processor and 8GB RAM. The IEEE 30 bus system is used for FACTS device placement in order to solve the multi-objective problem. Table 4.1 lists the specifications for the IEEE 30 and 14 bus systems. Table 4.2 depicts the population values for various optimization techniques.

Particular	Details	
	30 BUS	14 BUS
Transmission lines	41	20
Transformers	4 locations {6-9, 6-10, 4-12 and 27-28}	3 locations (6-11, 6-12, 6-9)
Shunt compensators	9 locations {10, 12, 15, 17, 20, 21, 23,24 and 29}	2 locations (10, 12)
Generators	6 buses {1, 2, 5, 8, 11, 13}	5 buses (1,2,5,8,11)

Table 4.1. Specifications of the IEEE 14 & 30 bus system

Methods	Population count
Particle Swarm Optimization	20
Harmony Search algorithm	25
Grey Wolf Optimization	18
Whale optimization	30
Hybrid KGMO-CSA	50

Table 4.2 Population Count for Optimization Methods

4.1.1 30 Bus System

The hybrid KGMO-CSA method's performance is evaluated in terms of TVD, power loss, line loading, and device cost. In terms of performance, five different scenarios are examined.

1. In 1st scenario, the system is evaluated without any devices.
2. In 2nd scenario, the system is investigated only with SVC.
3. 3rd scenario, the system is investigated only with TCSC
4. 4th scenario, the system is investigated only with UPFC.
5. 5th scenario, the system is investigated with SVC, TCSC, UPFC.

Control Variables	Initial Values	Optimal Values
V1	1.0500	1.0439
V2	1.0400	1.0198
V5	1.0100	1.0099
V8	1.0100	1.0262
V11	1.0500	1.0296
V13	1.0500	1.0323
T11	1.0780	0.9541
T12	1.0690	1.0247
T15	1.0320	0.9943
T36	1.0680	0.9615
Qc10	0.0000	3.5583
Qc12	0.0000	2.8731
Qc13	0.0000	2.2694
Qc17	0.0000	2.6702
Qc20	0.0000	2.8385
Qc21	0.0000	2.7782
Qc23	0.0000	3.0416
Qc24	0.0000	3.1675
Qc29	0.0000	1.2411
TVD (p.u)	1.47	0.1915
Ploss (MW)	5.74	5.2343
LL	6.42	5.353

Table 4.3 Performance analysis for Scenario 1

The performance of Scenario 1 for a 30-bus system is shown in Table 4.3. There are no FACTS devices considered in this case to solve the RPD problem. For the transmission system without FACTS devices, the values of TVD, Ploss, and LL are 0.1915 p.u., 5.2343 MW, and 5.353, respectively. Figure 4.1 depicts the fitness graph for scenario 1.

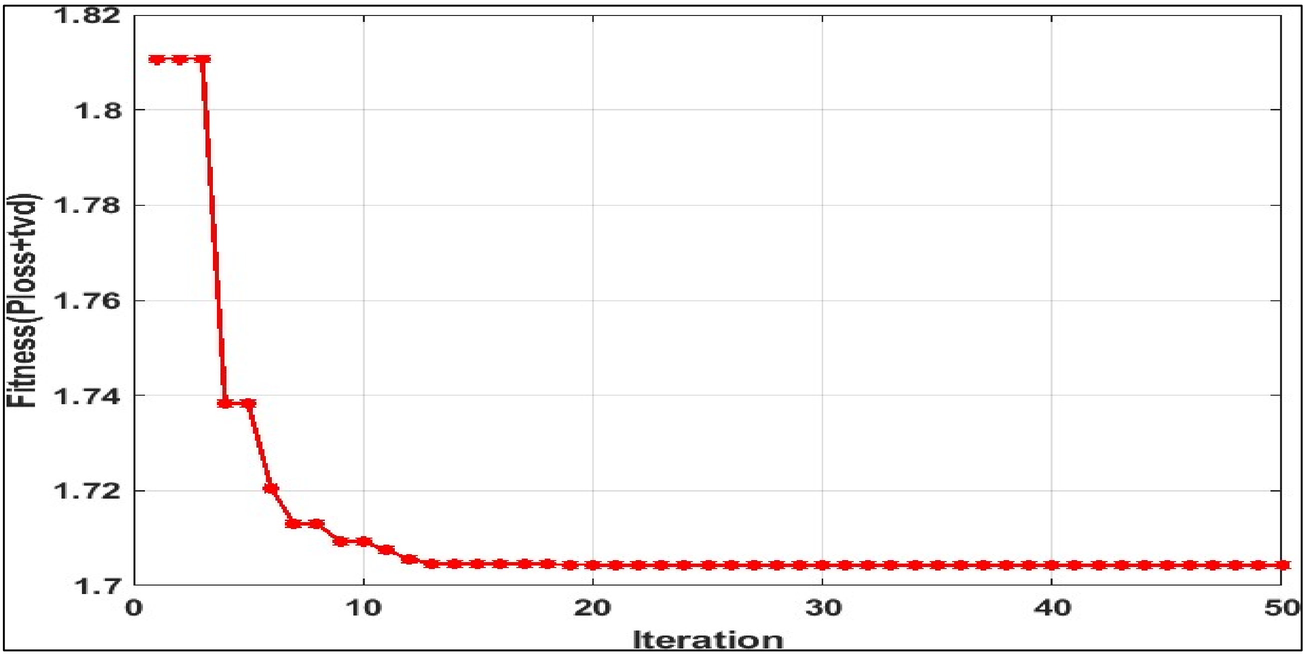

Figure 4.1 Fitness function for scenario 1

Control Variables	Initial Values	Optimal Values
V1	1.0500	1.0299
V2	1.0400	1.0390
V5	1.0100	1.0331
V8	**1.0100**	**1.0087**
V11	**1.0500**	**1.0292**
V13	**1.0500**	**0.9909**
T11	**1.0780**	**0.9982**
T12	**1.0690**	**0.9928**
T15	**1.0320**	**0.9537**
T36	**1.0680**	**0.9801**

Qc10	**0.0000**	**2.1377**
Qc12	**0.0000**	**1.5403**
Qc13	**0.0000**	**2.2657**
Qc17	**0.0000**	**3.5854**
Qc20	**0.0000**	**3.0387**
Qc21	**0.0000**	**2.4162**
Qc23	**0.0000**	**3.1345**
Qc24	**0.0000**	**2.6004**
Qc29	**0.0000**	**2.4739**
SVC location	**15.0000**	**15.0000**
SVC size	**0.0000**	**0.2557**
SVC cost ($/MVAR)	**-**	**127.365**
TVD (p.u)	**1.47**	**0.1274**
Ploss (MW)	**5.74**	**4.5435**
LL	**6.42**	**3.9129**

Table 4.4 Performance analysis for Scenario 2

Table 4.4 provides the scenario 2 performance analysis. For 30 buses with SVC alone, the findings are shown in Table 5. For scenario 2, the corresponding TVD, Ploss, and LL values are 0.1274 p.u., 4.5435 MW, and 3.9129. The SVC's size and location are 15 and 0.2557, respectively. The SVC employed in this scenario 2 costs 127.365 $/MVAR in addition. According to Table 4, scenario 2 has lower TVD, Ploss, and LL values than scenario 1. The graph of the fitness function for Scenario 2 is shown in Figure 4.2

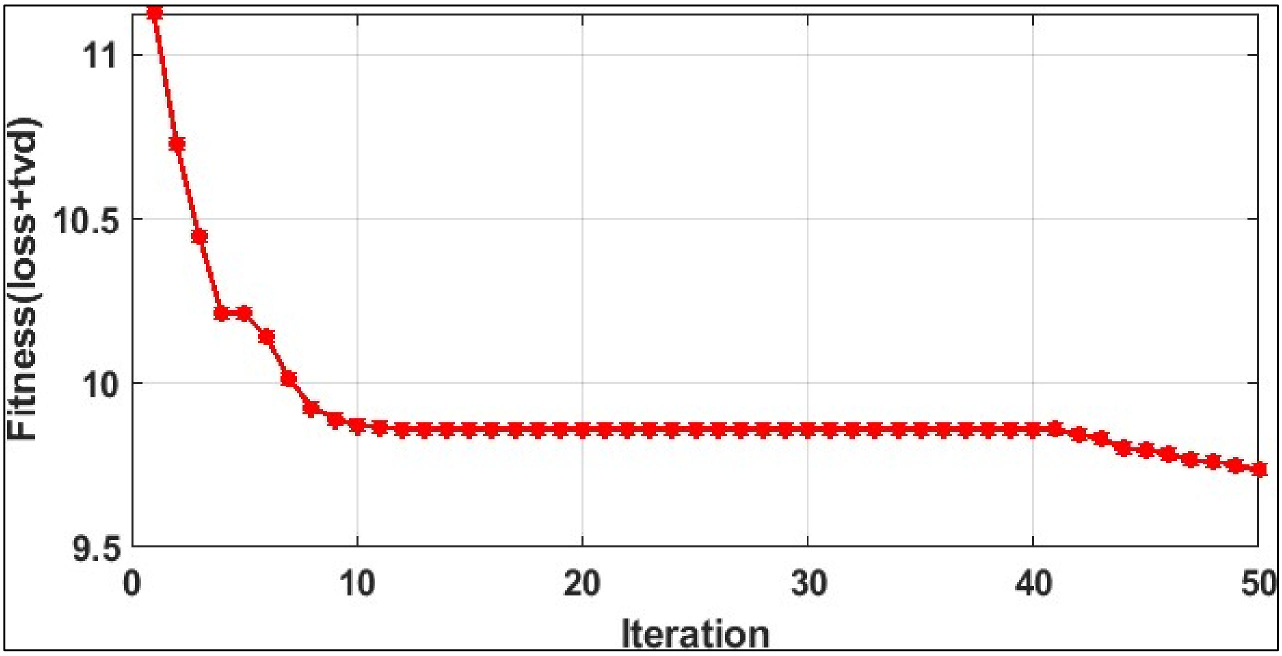

Figure 4.2 Fitness function for scenario 2

Control Variables	Initial Values	Optimal Values
V1	1.0500	0.9862
V2	1.0400	1.0644
V5	1.0100	1.0676
V8	1.0100	1.0289
V11	1.0500	1.0653
V13	1.0500	0.9691
T11	1.0780	1.0550
T12	1.0690	0.9000
T15	1.0320	0.9683
T36	1.0680	0.9690
Qc10	0.0000	2.9367
Qc12	0.0000	2.3654

Qc13	0.0000	5.0000
Qc17	0.0000	4.0393
Qc20	0.0000	2.4885
Qc21	0.0000	4.4321
Qc23	0.0000	0.0992
Qc24	0.0000	3.2304
Qc29	0.0000	2.4741
TCSC location	15.0000	16.0000
TCSC size	0.0000	0.137
TCSC cost ($/MVAR)	-	154.3736
TVD (p.u)	1.47	0.1077
Ploss (MW)	5.74	4.217
LL	6.42	4.9755

Table 4.5. Performance analysis for Scenario 3

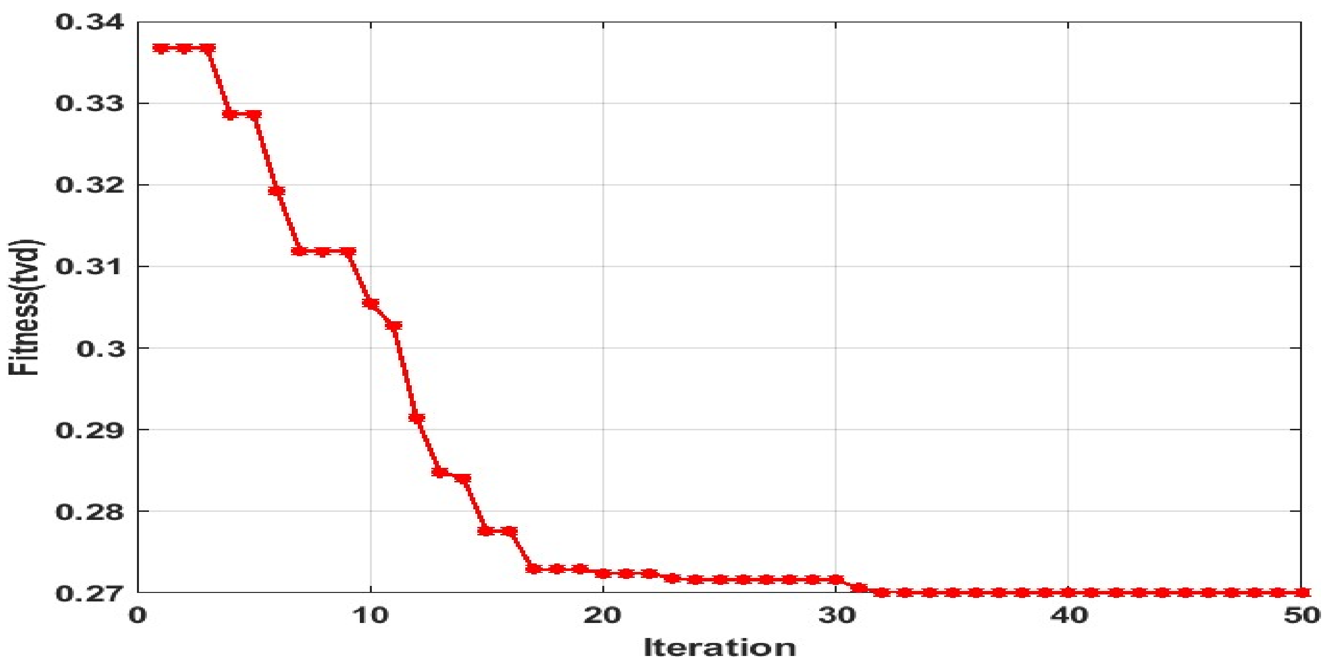

Figure 4.3 Fitness function for scenario 3

Figure 4.3 depicts the fitness graph for scenario 3. The effectiveness of scenario 3 for 30 buses is displayed in Table 4.5. For transmission systems using TCSC, the values of TVD, Ploss, and LL are 0.1077 p.u., 4.217 MW, and 4.9755, respectively. The TCSC is 16 miles away and 0.137 square miles in size. Furthermore, TCSC in the bus system costs 154.3736 $/MVAR.

Control Variables	Initial Values	Optimal Values
V1	1.0500	1.0534
V2	1.0400	1.0650
V5	1.0100	1.0196
V8	1.0100	1.0479
V11	1.0500	1.0503
V13	1.0500	0.9788
T11	1.0780	0.9567
T12	1.0690	1.0540
T15	1.0320	0.9861
T36	1.0680	0.9970
Qc10	0.0000	1.9261
Qc12	0.0000	0.7125
Qc13	0.0000	0.2863
Qc17	0.0000	0.7656
Qc20	0.0000	3.2344
Qc21	0.0000	2.7643
Qc23	0.0000	2.3348
Qc24	0.0000	1.6346
Qc29	0.0000	3.0487
UPFC location	0.0000	27.0000
UPFC size	0.0000	0.9866

UPFC degree	0.0000	0.558
UPFC impedance	0.0000	0.1021
UPFC cost ($/MVAR)	-	187.7069
TVD (p.u)	1.47	0.1014
Ploss (MW)	5.74	3.940
LL	6.42	3.6168

Table 4.6 Performance analysis for Scenario 4

Table 4.6 provides the performance analysis of scenario 4. For scenario 4, the corresponding values for TVD, Ploss, and LL are 0.1074 p.u., 3.940 MW, and 3.6168. The UPFC is 27 miles away and is 0.9866 square miles in size. Additionally, the price per MVAR for the UPFC employed in this scenario 4 is 187.7069. Table 6 reveals that scenario 4's TVD, Ploss, and LL values are lower than those of scenarios 1 and 2. The fitness function graph for Scenario 4 is shown in Figure 4.4

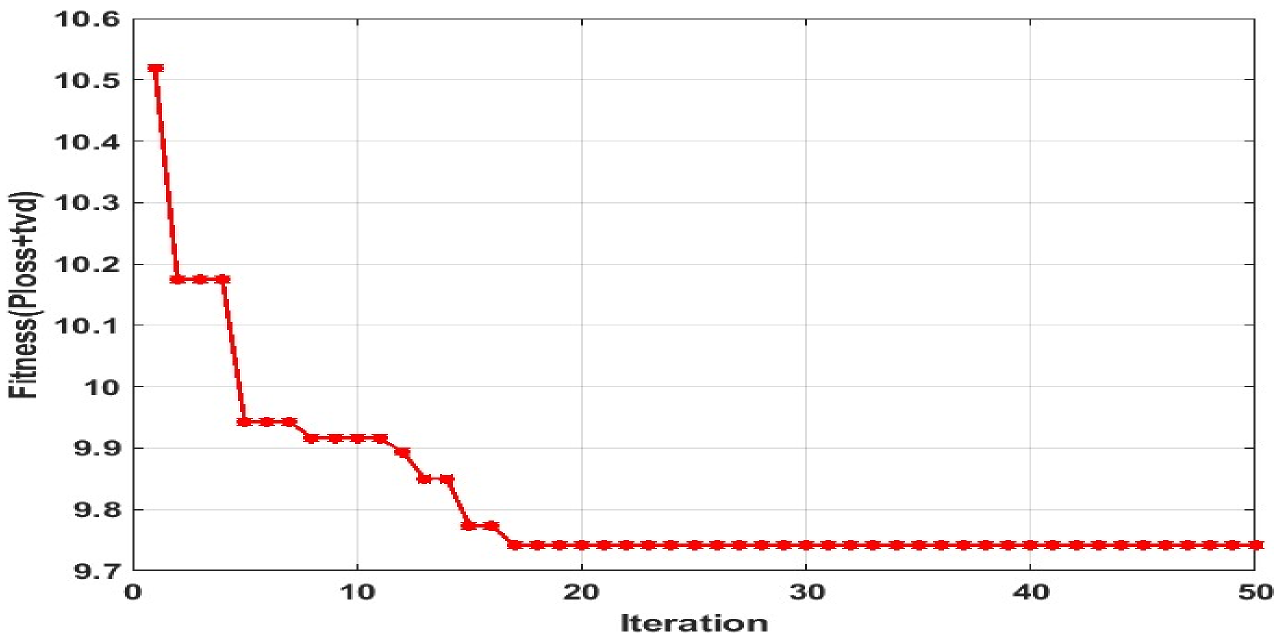

Figure 4.4 Fitness function for scenario 4

Control Variables	Initial Values	Optimal Values
V1	1.0500	0.9564
V2	1.0400	0.9770
V5	1.0100	1.0706
V8	1.0100	1.0251
V11	1.0500	0.9574
V13	1.0500	0.9951
T11	1.0780	0.9515
T12	1.0690	0.9684
T15	1.0320	1.0076
T36	1.0680	1.0236
Qc10	0.0000	0.6943
Qc12	0.0000	4.0131
Qc13	0.0000	2.6516
Qc17	0.0000	3.1690
Qc20	0.0000	1.4142
Qc21	0.0000	3.6634
Qc23	0.0000	2.1248
Qc24	0.0000	2.9427
Qc29	0.0000	1.9355
SVC location	0.0000	16.0000
SVC size	0.0000	41.2602
TCSC location	0.0000	25.0000
TCSC size	0.0000	0.974
UPFC location	0.0000	6.0000
UPFC size	0.0000	0.9943
UPFC degree	0.0000	0.3352
UPFC impedance	0.0000	0.64
SVC cost ($/MVAR)	-	129.1645
TCSC cost ($/MVAR)	-	152.7372

UPFC cost ($/MVAR)	-	187.8794
TVD (p.u)	1.47	0.1007
Ploss (MW)	5.74	3.6442
LL	6.42	4.1659

Table 4.7 Performance analysis for Scenario 5

Table 4.7 displays the 30 bus results together with all relevant information, including SVC, TCSC, and UPFC. For scenario 5, the corresponding values for TVD, Ploss, and LL are 0.1007 p.u., 3.6442 MW, and 4.1659, respectively. The IEEE 30 bus systems, which are located at 16, 25, and 6, respectively, are where SVC, TCSC, and UPFC are located. The sizes of the SVC, TCSC, and UPFC that are optimised by the proposed KGMO-CSA are 41.2602, 0.974, and 0.9943, respectively. Also included in this scenario are the expenses of the SVC, TCSC, and UPFC, which are 129.1645, 152.7372, and 187.8794 $/MVAR, respectively. According to Table 8, scenario 5's TVD and Ploss are lower than those of scenarios 1, 2, and 3. Figure 4.5 shows how the fitness function works.

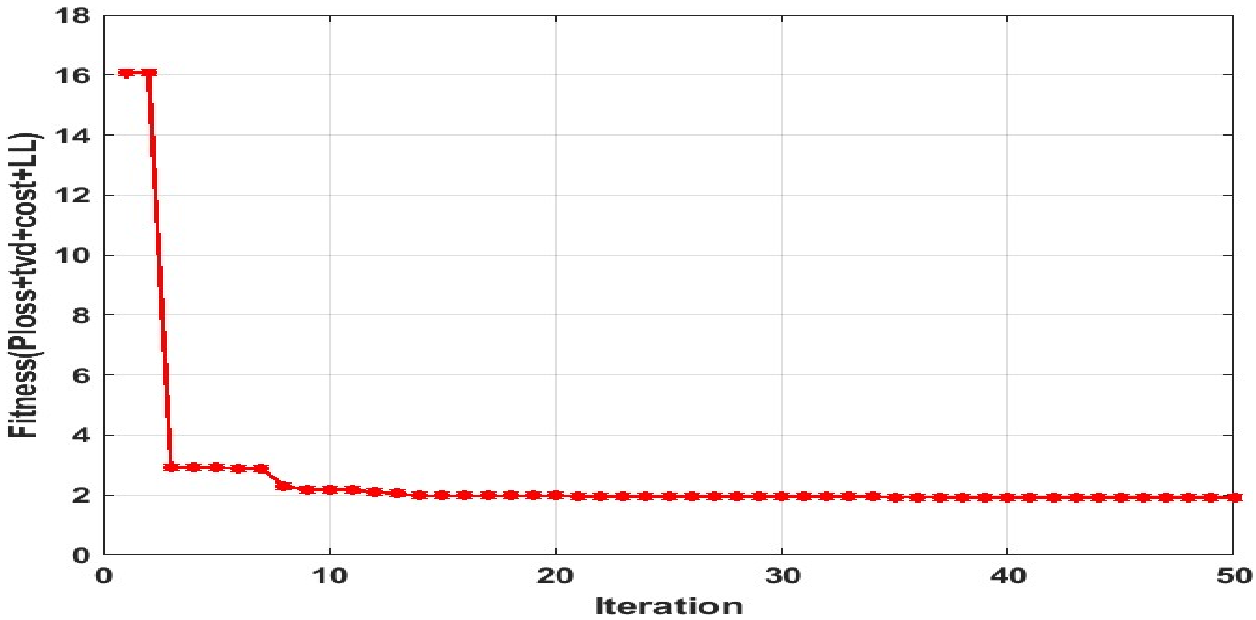

Figure 4.5 Fitness function for scenario 5

4.1.2 14 Bus System

Analysis of the hybrid KGMO-CSA method's behavior is done in terms of TVD, power loss, line loading, and device cost. The three alternative scenarios used for the performance analysis are as follows: With SVC, SVC and TCSC, and SVC, TCSC, and UPFC, respectively. The 14 bus with all FACTS, including SVC, TCSC, and UPFC, is included in the final scenario.

Symbol	Without SVC	KGMO_CSA_SVC
V1	1.0677	1.0742
V2	1.0659	1.0364
V5	0.9777	0.9856
V8	1.0528	1.0346
V11	1.0611	0.9901
T11	0.9798	0.9913
T12	1.0629	1.0100
T15	0.9354	0.9716
Qc10	1.2431	1.7566
Qc12	4.6983	1.0945
SVC location	-	2.000
Size	-	5.2833
TVD(P.U)	13.3822	13.1275
PLOSS (MW)	0.3407	0.2759

Table 4.8 Performance analysis of TVD and PLOSS of SVC for IEEE 14 bus system

Bus voltage at each bus	
Without FACTS	With FACTS
1	1.0014
0.997013516	0.9993
0.982830187	0.9903
0.975301886	0.9866
0.96785835	0.9831
0.949340982	0.9731
0.945849362	0.9697
0.93215167	0.9563
0.925803365	0.9502
0.919931487	0.9444
0.919055081	0.9436
0.917527092	0.9421
0.911347548	0.9361
0.909073448	0.9338

Table 4.9 Bus voltage for each line

Symbol	Initial	TVD, PLOSS and COST comparison		
		KGMO_CSA_SVC	KGMO_CSA_TCSC	KGMO_CSA_SVC_TCSC
V1	1.0500	1.0512	1.0421	1.0976
V2	1.0400	1.0240	1.0354	1.0893
V5	1.0100	1.0423	1.0131	1.0385
V8	1.0100	1.0243	1.0510	1.0369
V11	1.0500	1.0335	1.0012	0.9999
T11	1.05	0.9820	0.9982	0.9751
T12	1.078	0.9934	0.9758	0.9816
T15	1.069	0.9798	0.9885	0.9188
Qc10	1.032	2.2181	2.1545	2.0307
Qc12	1.068	1.1679	2.1983	3.0980
SVC location	-	12	-	2.0000
SVC size	-	41.4525	-	31.25
SVC cost	-	115.2525	-	98.3626
TCSC location	-	-	10	3.0000
TCSC size	-	-	8.1524	9.0660
TCSC cost	-	-	143.2637	149.6199
Total cost	-	115.2525	143.2637	247.982
TVD		0.1321	0.1970	0.1195
PLOSS	13.49	12.5924	12.9923	12.4163

Table 4.10 Performance analysis of SVC & TCSC for IEEE 14 bus system

According to Table 4.10, which summarizes the performance study of Case 2 for the 14 bus, the KGMO algorithm with FACTS devices performs better for the RPD problem than the KGMO algorithm without FACTS devices. It demonstrates that utilizing KGMO CSA for SVC and TCSC placement is preferable to alternative options. In contrast to other cases, the PLOSS of KGMO CSA employing both SVC and TCSC is 12.4163 MW, which is lower.

Symbol	Initial	PLOSS, TVD, Line Loading Index and COST			
		KGMO_CSA_SVC	KGMO_CSA_TCSC	KGMO_CSA_UPFC	KGMO_CSA_SVC_TCSC_UPFC
V1	1.0500	1.0532	1.0121	1.0823	1.0504
V2	1.0400	1.0218	1.0521	1.1000	1.0385
V5	1.0100	0.9659	0.9962	1.0428	1.0162
V8	1.0100	1.0244	0.9854	0.9791	1.0274
V11	1.0500	1.0245	0.9987	0.9984	1.0302
T11	1.05	0.9824	1.0111	0.9719	1.0136
T12	1.078	0.9900	0.9784	1.0497	1.0483
T15	1.069	0.9775	0.9884	0.9525	0.9954
Qc10	1.032	2.5687	2.1546	1.2911	2.5728
Qc12	1.068	1.8607	2.3651	0.0983	3.0497
SVC location	15.000	6.0000	-	-	5.0000
SVC size	0.0000	39.6186	-	-	19.7086
SVC cost	-	139.9346	-	-	127.3800
TCSC location	15.000	-	11.0000	-	14.0000
TCSC size	0.000	-	5.3621	-	0.0262
TCSC cost	-	-	146.2232	-	153.7500
UPFC location	0.000	-	-	9.0000	1.0000
UPFC size	0.000	-	-	0.9500	0.5135
UPFC cost	-	-	-	188.2244	188.2200

Total cost	-	-	-	-	469.3500
TVD		0.1375	0.1321	0.12792	0.1066
PLOSS	13.49	13.4125	13.2401	13.1306	12.0133
LL	15.968	15.636	16.5599	14.563	14.0121

Table 4.11 Performance analysis of SVC, TCSC & UPFC for IEEE 14 bus system

The performance analysis of PLOSS, TVD, COST, and LL reduction for the IEEE 14 bus system is shown in Table 4.11. The suggested KGMO CSA easily reaches the optimal point at the lowest iteration count, as can be shown from the Table 4.11. It demonstrates that the KGMO CSA is superior to other scenarios when all three placements—SVC, TCSC, and UPFC—are used together. For instance, the PLOSS of the KGMO scenario with SVC, TCSC, and UPFC is 12.0133 MW, which is lower than the PLOSS of the KGMO CSA scenario with only SVC or the PLOSS of the KGMO scenario with both SVC and TCSC.

4.1.3 57 Bus System

Once the STATCOM connection is transferred from the PV bus to the PQ bus, the boundary conditions in the STATCOM are broken. In this scenario, the reactive power produced or absorbed would correspond to the limit that was breached. The STATCOM is modelled in this study as a voltage source throughout the whole operating range, enabling a strict voltage support mechanism. IEEE 57 buses typically consist of 80 transmission lines, 50 load buses, and 7 generator buses. The total load demand is 1195.8 MW and 319.4 MVAR, and Bus 1 is marked as a slack bus. Using the suggested KGMO CSA approach, the ideal placement and sizing of four FACTS devices are started for the IEEE 57 bus.

Parameters	GWO	QOGWO	Proposed KGMO_CSA
T(59)	1.05	1.05	1.05
T (31)	1.0385	0.984	1.024
T(73)	1.0371	1.05	1.05
T(37)	1.0336	1.05	1.05
T(76)	0.9905	1.05	0.9
T(36)	0.9263	0.9069	0.9
T(35)	0.9197	0.9066	0.9139
T (19)	0.9145	0.9068	0.9
T(54)	0.9109	0.9519	0.9
T(46)	0.9058	0.9012	0.9
T(71)	0.9051	0.9	0.9
T (20)	0.9041	0.9026	0.9
T(80)	0.9024	0.9068	0.9
T(58)	0.9002	0.9	0.8902
T(41)	0.9	0.9	0.8926
T(65)	0.9	0.9	0.8917
T(66)	0.9	0.9	0.8913
Qg (6)	0.1926	0.0731	-0.091
Qg (3)	0.1785	0.5682	0.1257
Qg (9)	0.0049	-0.0014	0.0295
Qg (12)	0.0026	1.1004	1.55
Qg (8)	-0.103	1.0292	0.8128
Qg (2)	-0.1258	-0.0402	0.5
TCSC (1)	0.0123(37)	0.032391(37)	0.154100(27)
SVC (1)	0.20(23)	0.1179(23)	0.3(25)
UPFC (1)	0.725 (41)	0.628 (41)	0.462 (41)
STATCOM (1)	0.5 (26)	0.481 (26)	0.331(26)
PLoss	**0.2097**	**0.2086**	**0.2059**
CTotal	$\mathbf{1.109} \times 10^7$	$\mathbf{1.01899} \times 10^7$	$\mathbf{1.09792} \times 10^7$

Table 4.12 Performance analysis of SVC, TCSC, UPFC and STATCOM for IEEE 57 bus system

The IEEE 57-bus system is configured with SVC, TCSC, and STATCOM at the best possible location according to Table 13. Real power loss at the outset without planning is 27.99 MW, and its operating cost is 1.471 107. According to Table 4.12, the suggested method's perceived ineffective lines, 27 and 41, are where the TCSCs and UPFCs are located, while buses 25 and 26 are where the SVC and STATCOM devices are located. The suggested KGMO CSA method outperforms the other GWO and QOGWO approaches with a lower cost of 1.09792 107 and a reduced power loss of 0.2059. The values for statistical inference are tabulated in Table 4.13

Mean	Medium	Mean Deviation	Variance	SD	Best	Worst	Standarderror	Convergence	Confidenceinterval	Length of confidence interval
5.13	3.731	1.402	1.1158	0.622	10.62	8.335	0.017	1.3253	0.52	1

Table 4.13 Statistical Inference Values

4.2 Comparative analysis

The behavior of KGMO-CSA is compared to earlier methods to assess how effective the hybrid KGMO-CSA method is. In terms of TVD and power loss, the hybrid KGMO-CSA technique is validated. The current methods are hybrid KGMO-PSO [17] and QOCRO [16]. The hybrid KGMO-CSA method's comparative analysis is also confirmed for the IEEE 30 bus system. The goal of QOCRO in [16] is to secure the best TCSC and SVC places. The placements and sizes of SVC, TCSC, and UPFC are determined using the hybrid optimization of KGMO and PSO [17]

Parameters	QOCRO [16]	KGMO-PSO [17]	Hybrid KGMO-CSA
TVD (p.u)	0.1039	0.1167	0.1007
Ploss (MW)	-	3.8786	3.6442

Table 4.14 Comparative analysis of the hybrid KGMO-CSA method for 30 bus

Table 4.14 compares the hybrid KGMO-CSA approach with QOCRO [16] and the hybrid KGMO-PSO method with QOCRO [17]. The hybrid KGMO-CSA achieves reduced TVD and power loss than the QOCRO [16] and hybrid KGMO-PSO [17], according to the aforementioned data. For instance, the TVD of the KGMO-CSA technique is 0.1007 p.u., which is lower than the TVDs of the hybrid KGMO-PSO [17] and QOCRO [16]. The QOCRO [16] fails to take line loading and generation cost into account while determining the best location for FACTS devices. Furthermore, for large-dimensional space, the PSO of the hybrid KGMO-PSO [17] is small. The hybrid KGMO-CSA technique, on the other hand, considers four different goal functions: generating cost, total voltage variation, line loading, and real power. Thus,the hybrid KGMO-CSA provides significant results for optimal placement due to less computational complexity.

Scenario	Objective case	PSO	WIPSO [21]	KGMO_CSA
With SVC	TVD	0.1453	0.1411	0.1321
	Ploss	11.989	12.233	12.59
	LL	18.423	16.986	16.7858
	All + Cost	Tvd =0.1399	Tvd =0.1387	Tvd =0.1375
		Ploss = 14.018 LL = 15.663 Cost = 178.5896	Ploss = 13.764 LL = 15.639 Cost =166.6414	Ploss= 13.4125 LL = 15.6364 Cost = 138.8588
With TCSC	TVD	0.1732	0.1847	0.1970
	Ploss	14.186	13.923	12.9923
	LL	16.279	15.849	15.6539
	All + Cost	Tvd = 0.1365 Ploss = 14.858 LL = 17.384 Cost =153.7692	Tvd = 0.1381 Ploss = 13.176 LL = 17.0087 Cost =149.6985	Tvd = 0.1321 Ploss = 13.2401 LL = 16.5599 Cost = 149.3659

With UPFC	TVD	0.1211	0.1223	`
	Ploss	13.987	12.526	12.4163
	LL	13.685	13.778	13.5215
	All + Cost	Tvd= 0.1814 Ploss = 12.654 LL = 15.001 Cost =188.2348	Tvd= 0.1111 Ploss = 12.391 LL = 14.898 Cost =182.5484	Tvd= 0.1146 Ploss = 12.1385 LL = 14.563 Cost = 181.4551
With SVC, TCSC, UPFC	TVD	0.1252	0.1148	0.1136
	Ploss	12.589	12.433	12.2133
	LL	15.063	15.012	14.9286
	All + Cost	Tvd= 0.1846 Ploss = 12.386 LL = 15.923 Cost =496.5987	Tvd= 0.1566 Ploss = 12.125 LL = 14.889 Cost =487.7889	Tvd= 0.1066 Ploss = 12.0133 LL = 14.0121 Cost = 483.1463

Table 4.15 Comparative analysis for IEEE 14 bus system

The comparison of the KGMO CSA, PSO, and WIPSO [21]-based allocations for the IEEE 14 bus system is shown in Table 4.15. Four alternative situations are compared: the bus system with SVC, the bus system with TCSC, the bus system with UPFC, and the bus system with all FACTS devices. According to the comparison, the IEEE 14 bus with FACTS devices performs better than the system without FACTS devices.

IEEE 57-Bus	Proposed KGMO_CSA Method	PSO based GSA	GA	HBA	BFA
SVC	1.64	--		0.98	0.93
TCSC	2.19	1.653	1.26	0.19	0.11
UPFC	8.93	--	--	0.75	0.56

Table 4.16 Performance between proposed and existing methods for Real power loss savings [22]

The results of comparing the proposed method with evolutionary-based computational methods, such as the Genetic Algorithm (GA)-based Gravitational Search Algorithm, PSO, the Honey Bee Algorithm (HBA), and the Bacteria Foraging Algorithm (BFA) [22], for determining power losses and improving the voltage profile after FACTS assignment, are shown in Table 4.16.

Table 4.16 shows that KGMO-CSA has less real power loss than another optimization approach, which is a significant improvement.

4.3 Conclusion

Due to the liberalized approach to production control, security is now the main concern of the power system. In this study, power flow and voltage profiles serve as security indices. Security-related risks are primarily addressed using these indexes, and the FACTS are optimally distributed as compensation. On the other hand, poor FACTS allocation results in excessive current production and load summary interruption, which compromises security.

A hybrid KGMO-CSA approach is used in this study to determine the best size and placement of FACTS. When compared to QOCRO and hybrid KGMO-PSO, the TVD and power loss of the hybrid KGMO-CSA technique are lower. According to the findings, when compared to the current KGMO-PSO, the power loss of the hybrid KGMO-CSA technique is decreased by up to 6.04%, and TVD is reduced by up to 13.71%. It is evident from the simulation results that the hybrid KGMO-CSA approach is superior to the current QOCRO technique.

Future analysis of FACTS location and size in big bus systems like IEEE 85 and IEEE 118 can make use of cutting-edge optimization methods.