Chapter 4
Implementation

4.1 Test data

The ZBF, ZDP, LS, SA, GA, GA-SA, CGSA, and MOL methods are developed in *C* language and executed on a Pentium III 550 MHz with 128 MB RAM under Linux operating system. The algorithms are tested on the system consisting generating units with linear increasing IC, linear decreasing IC, increasing staircase IC, and decreasing staircase IC functions. The fuel cost, operating limit, ramp rate and coefficients of input-output functions are in Table 4.1. The input-output function is given as $A_i + B_iP_i + C_iP_i^2$ and the generator cost function is the product of the input-output function and the fuel cost. The cost functions and IC functions of those generating units are also shown in Figures 4.1 and 4.2. The scaled EGAT daily load curves for the 10, 20, 40 and 80 generating unit systems are used. The EGAT daily load curve scaled for the 20 generating unit system is shown in Figure 4.3. The scaled EGAT daily load demand for the 10 generating unit system is given in Appendix A.

Table 4.1 Input-output characteristics of Rayong CC (RY_CC), Bangpakong thermal (BPK_T), Khanom CC (KN_CC), and Independent Power (IPT) CC units

Unit	P_{min} (MW)	P_{int} (MW)	P_{max} (MW)	Fuel cost (Baht/Gcal)	Input-output coefficients (Gcal/Hour)			Ramp rate (MW/min)	
					A_i	B_i	C_i	UR_i	DR_i
RY_CC#1	100	-	300	273.80	-123.26930	3.1770742	-0.002752183	8	8
RY_CC#2	100	-	300		-127.79030	3.2410401	-0.003104120		
RY_CC#3	100	-	150		-30.27881	2.2650570	-0.000923850		
RY_CC#4	100	-	300		-127.79030	3.2410401	-0.003104120		
BPK_T#1	280	-	525.5	372.381	89.212409	2.158260	0.000111	5	5
BPK_T#2	280	-	526.5		106.132003	2.101667	0.000201		
BPK_T#3	280	-	576		134.028279	1.890687	0.000425		
BPK_T#4	280	-	576		80.666760	2.163603	0.000107		
KN_CC	376	495		315.143	113.5361104	1.856133141	0	8	8
		495	678		206.6947723	1.667493427	0		
IPT_CC	320	510	-	315.143	180.4651584	1.45977807	0	15	15
	-	510~650	-		79.4196883	1.65809420	0		
	-	650	700		-141.8048526	1.99828107	0		

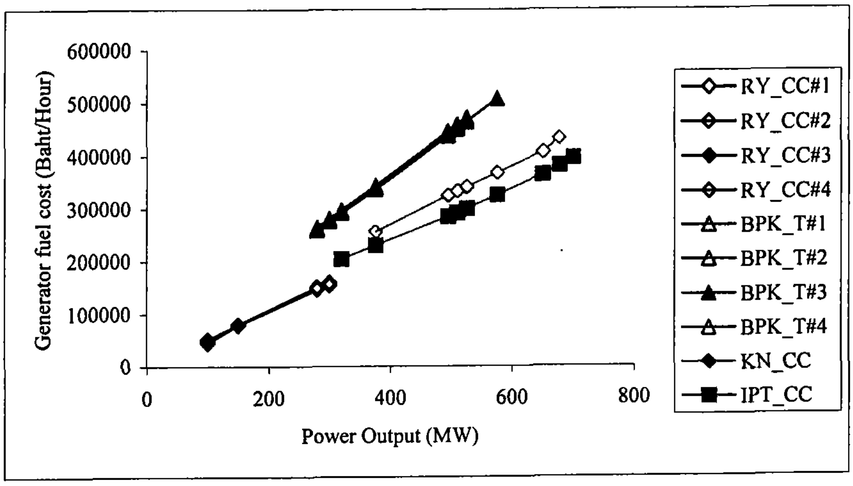

Figure 4.1 The generator fuel cost curves of RY_CC#1-4, BPK_T#1-4, KN_CC and IPT_CC generating units

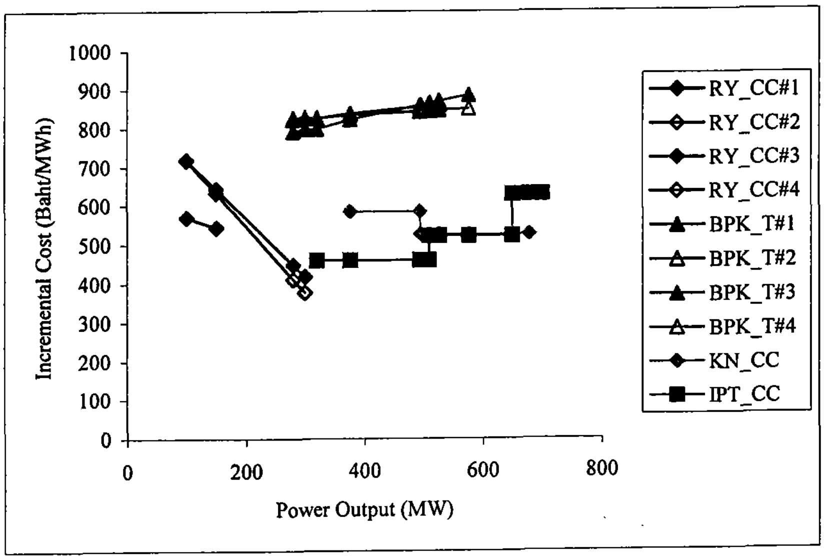

Figure 4.2 The incremental cost (IC) curves of RY_CC#1-4, BPK_T#1-4, KN_CC and IPT_CC generating units

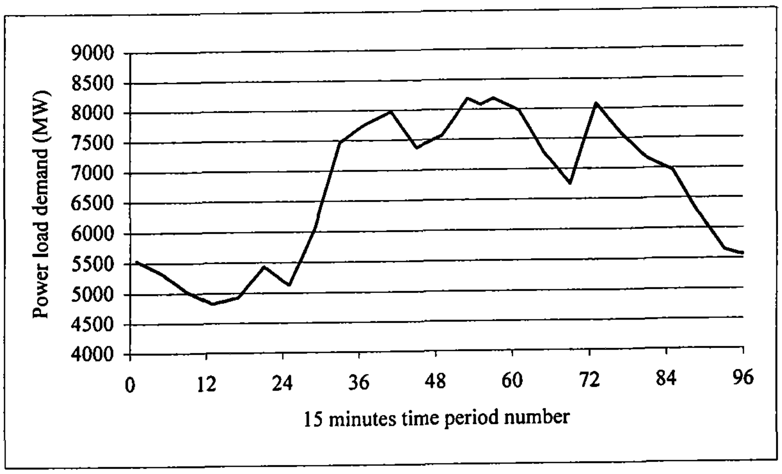

Figure 4.3 EGAT daily load curve scaled for the 20 generating unit system

Table 4.2 Ranges of monotonically increasing load demand for 10, 20, 40, and 80 generating unit systems

No. of units	Minimum load demand (MW)	Maximum load demand (MW)	Increasing step size (MW)	Number of time periods (T)
10	2,220	4,500	10	228
20	4,400	9,070	10	467
40	8,780	18,160	20	469
80	17,560	36,320	40	469

Two types of load demand curves are used namely, the monotonically increasing load demand, and daily load demand. Table 4.2 shows the ranges of monotonically increasing load demand for 10, 20, 40, and 80 generating unit systems. The load demands increase from the minimum loads to the maximum loads with the given step sizes.

The 20, 40, and 80 generating unit systems use the multiples of the RY_CC, KN_CC, IPT_CC and BPK_T input-output data. The B-matrices for any given system size are generated so that transmission line losses are in the range of 1% to 2.1% of total load demand. The B-matrix coefficients of 10 generating unit system are given in Appendix A.

4.2 Parameter selections

The ZBF and ZDP method run on 10 generating unit system has the factor K_Δ and the initial step size Δ_1, equal to 5 and 100 while the maximum number of iteration is 7 and 8, respectively. Table 4.3 shows SA, LS, GA-SA, CGSA and GA parameters. SA and LS have the number of trials (m_{max}), and initial searching boundary (σ_1) whereas GA-SA and GA have the same population size (NP), crossover probability, mutation probability and maximum number of generations (G_{max}). To demonstrate the performance of CGSA over the others, G_{max}, m_{max}, and σ_1 are only 100, 500, and 18, respectively.

Table 4.3 Parameter settings for SA, LS, GA-SA, CGSA and GA

Method	Pop. Size (NP)	Crossover probability	Mutation probability	Maximum no. of generations (G_{max})	No. of trials (m_{max})	σ_I	Epoch generation
SA	-	-	-	-	1000	100	-
LS	-	-	-	-	1000	100	-
GA-SA	56	0.5	0.01	1000	1000	100	-
CGSA	56	0.5	0.01	100	500	18	12
GA	56	0.5	0.01	1000	-	-	-

4.3 Experimental results

For 80 generating unit system at the power demand of 30,000 MW, with the same initial solution, CGSA converges at a faster rate than GA, GA-SA, SA, and LS as shown in Figure 4.4.

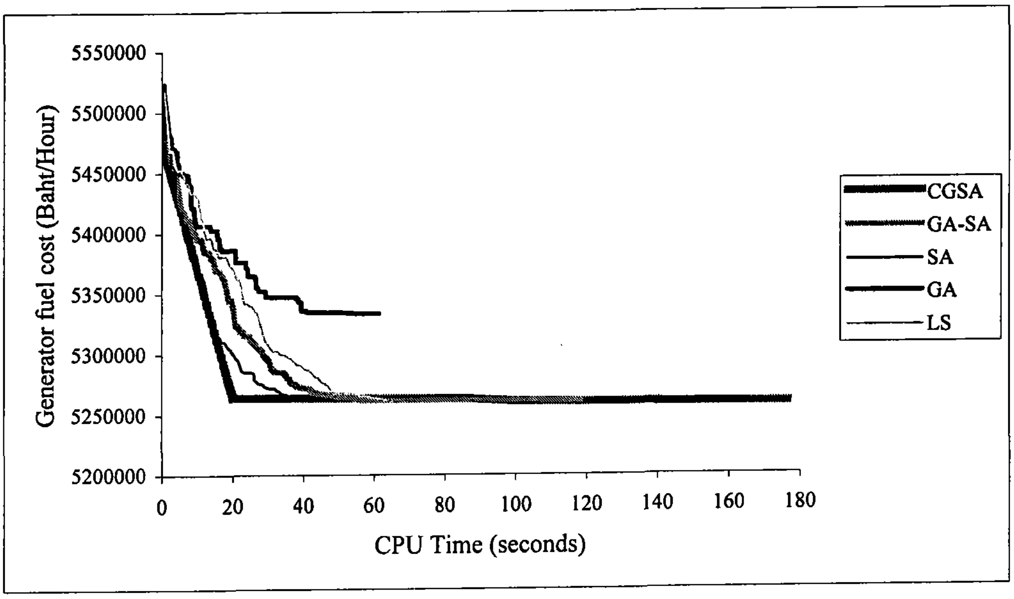

Figure 4.4 Convergence comparison of the 80 generating unit system with 30,000 MW load demand

For both monotonically increasing load demands and daily load demands, the least and average total generator fuel costs among 10 runs with 10 different seed numbers of CGSA are cheaper than the other algorithms on all generating unit systems as shown in Tables 4.4 and 4.5. The variation of the total generator fuel cost obtained from CGSA, GA-SA, GA, SA and LS on 10 generating unit system with monotonically increasing load demand are shown in Figure 4.5. Obviously, CGSA total generator fuel costs are more economical than those of the other algorithms in all seed numbers.

To compare the total generator fuel cost of CGSA to GA alone and SA alone with the same CPU times, GA and SA parameters are adjusted so that they require the same CPU times as that of CGSA. For the 10 generating unit system, GA* uses the maximum allowable number of 1,450 generations whereas SA* uses the maximum number of trials per iteration of 3,320. As shown in the tables, GA* and SA* cannot find as good solutions as CGSA solutions.

Table 4.4 Comparisons of total generator fuel costs from 10 runs for 10, 20, 40 and 80 generating unit systems with monotonically increasing load demands

No. of units	Method	Least total generator fuel cost (Baht)	Avg. total generator fuel cost (Baht)	Avg. total generator fuel cost difference from CGSA	% Avg. total generator fuel cost difference from CGSA
10	CGSA	137,577,297	137,598,948	0	0.0000
	ZBF	137,606,175	137,606,175	7,227	0.0053
	GA-SA	137,599,375	137,642,287	43,339	0.0315
	SA*	137,647,904	137,678,005	79,057	0.0575
	ZDP	137,679,129	137,679,129	80,181	0.0583
	SA	137,642,269	137,688,965	90,017	0.0654
	LS	137,692,983	137,711,972	113,024	0.0821
	GA*	137,808,524	137,822,792	223,844	0.1627
	GA	137,821,705	137,852,686	253,738	0.1844
	MOL	138,026,055	138,026,055	427,107	0.3104
20	CGSA	562,832,338	562,878,657	0	0.0000
	GA-SA	563,177,508	563,210,950	332,293	0.0590
	SA	563,747,587	563,779,094	900,437	0.1600
	LS	563,861,276	563,957,716	1,079,059	0.1917
	GA	564,221,002	564,279,779	1,401,122	0.2489
	MOL	565,001,762	565,001,762	2,123,105	0.3772
40	CGSA	1,131,713,930	1,131,791,215	0	0.0000
	GA-SA	1,133,179,867	1,133,302,246	1,511,031	0.1335
	SA	1,134,610,975	1,134,694,824	2,903,609	0.2565
	LS	1,134,823,159	1,134,873,202	3,081,987	0.2723
	MOL	1,135,185,542	1,135,185,542	3,394,327	0.2999
	GA	1,136,020,008	1,136,092,285	4,301,070	0.3800
80	CGSA	2,266,618,582	2,266,880,289	0	0.0000
	GA-SA	2,268,904,652	2,269,031,539	2,151,250	0.0949
	MOL	2,269,852,713	2,269,852,713	2,972,424	0.1311
	SA	2,270,572,225	2,270,714,766	3,834,477	0.1692
	LS	2,270,949,724	2,271,028,404	4,148,115	0.1830
	GA	2,278,175,104	2,278,352,718	11,472,429	0.5061

Table 4.5 Comparisons of total generator fuel costs from 10 runs for 10, 20, 40 and 80 generating unit systems with daily load demands

No. of units	Method	Least total generator fuel cost (Baht)	Avg. total generator fuel cost (Baht)	Avg. total generator fuel cost difference from ZBF or CGSA	% Avg. total generator fuel cost difference from ZBF or CGSA
10	ZBF	58,076,859	58,076,859	0	0.0000
	ZDP	58,081,465	58,081,465	4,606	0.0079
	CGSA	58,071,600	58,082,616	5,757	0.0099
	GA-SA	58,081,085	58,089,485	12,626	0.0217
	SA*	58,082,808	58,089,348	12,489	0.0215
	SA	58,083,124	58,101,460	24,601	0.0424
	LS	58,100,083	58,120,741	43,882	0.0756
	GA*	58,165,376	58,181,429	104,570	0.1801
	GA	58,181,888	58,193,757	116,898	0.2013
	MOL	58,269,171	58,269,171	192,312	0.3311
20	CGSA	113,874,709	113,883,566	0	0.0000
	GA-SA	113,966,459	113,995,162	111,596	0.0980
	SA	114,093,699	114,117,900	234,334	0.2058
	GA	114,133,734	114,156,979	273,413	0.2401
	LS	114,150,208	114,169,518	285,952	0.2511
	MOL	114,332,935	114,332,935	449,369	0.3946
40	CGSA	227,692,214	227,715,435	0	0.0000
	GA-SA	228,026,525	228,049,922	334,487	0.1469
	SA	228,358,789	228,387,442	672,007	0.2951
	LS	228,394,009	228,414,677	699,242	0.3071
	MOL	228,450,426	228,450,426	734,991	0.3228
	GA	228,567,166	228,608,830	893,395	0.3923
80	CGSA	456,397,816	456,445,429	0	0.0000
	GA-SA	456,940,652	456,977,120	531,691	0.1165
	MOL	457,204,202	457,204,202	758,773	0.1662
	SA	457,303,849	457,346,174	900,745	0.1973
	LS	457,379,326	457,419,207	973,778	0.2133
	GA	459,028,066	459,146,978	2,701,549	0.5919

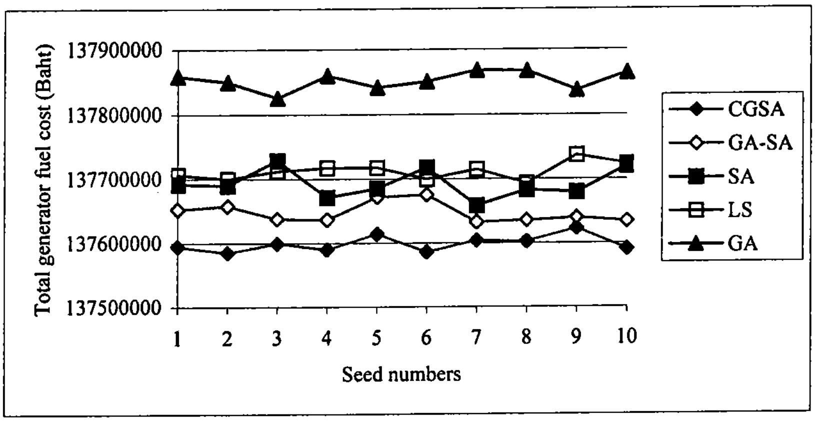

Figure 4.5 The total generator fuel cost of 10 different seed numbers of CGSA, GA-SA, GA, SA and LS for 10 generating unit system with monotonically increasing load demand

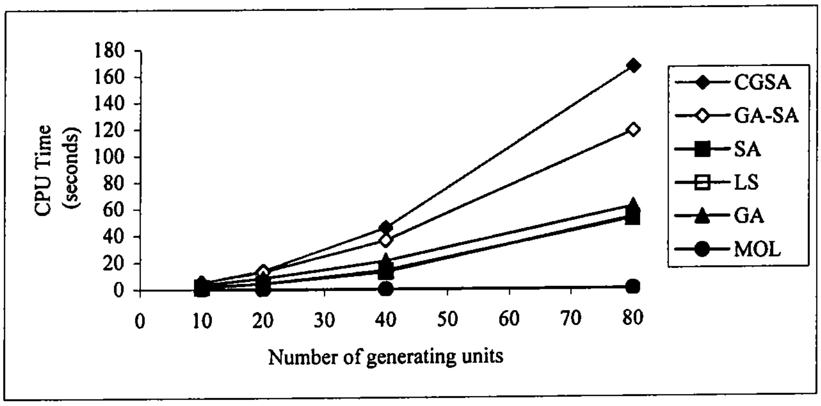

Figure 4.6 Comparison of CPU times per load demand

The average CPU times of these algorithms are shown in Figure 4.6. For the 10 generating unit system, the CPU times per load demand of ZBF, ZDP, CGSA, GA-SA, SA, LS, GA, and MOL are 5.2585, 0.2966, 5.3100, 5.3053, 1.7651, 1.5861, 3.5031, and 0.0004 seconds, respectively. For the 80 generating unit system, the CGSA CPU time of 153.09 seconds per load demand is still reasonable for ED problem.