MULTI-OBJECTIVE PARETO ANT COLONY SYSTEM BASED ALGORITHM FOR GENERATOR MAINTENANCE SCHEDULING

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Abstrak

Model penjadualan penyelenggaraan penjana (GMS) berbilang objektif sedia ada mengambilkira unit commitment bersekali dengan unit penyelenggaraan berdasarkan strategi penyelenggaraan berkala. Model-model tersebut tidak cekap kerana unit commitment tidak menjalani penyelenggaraan dan strategi berkala tidak dapat digunakan untuk pelbagai jenis penjana. Model graph sedia ada tidak dapat menjana penjadualan untuk GMS berbilang objective manakala algoritma Pareto Ant Colony System (PACS) tidak berupaya mempertimbangkan kedua-dua masalah secara berasingan. Satu algoritma PACS berbilang objektif berasaskan strateji berjujukan yang mempertimbangkan unit commitment dan GMS secara berasingan dicadangkan untuk mendapat penyelesaian kepada model GMS yang dicadangkan. Satu model graf juga dibangunkan untuk menjana penjadualan unit penyelenggaraan. Kaedah Taguchi dan Grey Relational Analysis dicadangkan untuk penalaan parameter PACS. Set data sistem IEEE RTS 26, 32 dan 36-unit digunakan dalam penilaian prestasi algoritma PACS. Prestasi algoritma PACS dibandingkan dengan empat algoritma penanda aras berbilang objektif termasuk Non-dominated Sorting Genetic, strength Pareto evolutionary, Simulated Annealing, and Particle Swarm Optimization menggunakan metrik gred hubungan kelabu (GRG), liputan, jarak ke hadapan Pareto, hamparan Pareto dan bilangan penyelesaian tidak didominasi. Ujian Friedman digunakan untuk menunjukkan kepentingan keputusan. Model GMS berbilang objektif lebih unggul daripada model penanda aras dalam menghasilkan jadual GMS dari segi fungsi objektif kebolehpercayaan dan pelanggaran dengan purata peningkatan antara 2.68% dan 92.44%. Ujian Friedman menggunakan metrik GRG menunjukkan prestasi yang lebih baik (nilai-$p<0.05$) untuk algoritma PACS berbanding algoritma penanda aras. Model dan algoritma yang dicadangkan boleh digunakan untuk menyelesaikan masalah GMS berbilang objecktif manakala nilai baharu untuk parameter boleh digunakan untuk mendapatkan penjadualan pennyelenggaraan penjana yang optimum atau hamper optimum. Model dan algoritma yang dicadangkan boleh digunakan pada pelbagai jenis unit penjanaan untuk meminimumkan ganguan tenaga dan memanjangkan jangka hayat unit.

Kata kunci: Strategi berurutan, Penyelenggaraan penjana, *Unit commitment*, Pengoptimuman, Model graf.

Abstract

Existing multi-objective Generator Maintenance Scheduling (GMS) models have considered unit commitment problem together with unit maintenance problem based on a periodic maintenance strategy. These models are inefficient because unit commitment does not undergo maintenance and periodic strategy cannot be applied on different types of generators. Present graph models cannot generate schedule for the multi-objective GMS models while existing Pareto Ant Colony System (PACS) algorithms were not able to consider the two problems separately. A multi-objective PACS algorithm based on sequential strategy which considers unit commitment and GMS problem separately is proposed to obtain solution for a proposed GMS model. A graph model is developed to generate the units' maintenance schedule. The Taguchi and Grey Relational Analysis methods are proposed to tune the PACS's parameters. The IEEE RTS 26, 32 and 36-unit dataset systems were used in the performance evaluation of the PACS algorithm. The performance of PACS algorithm was compared against four benchmark multi-objective algorithms including the Non-dominated Sorting Genetic, Strength Pareto Evolutionary, Simulated Annealing, and Particle Swarm Optimization using the metrics grey relational grade (GRG), coverage, distance to Pareto front, Pareto spread, and number of non-dominated solutions. Friedman test was performed to determine the significance of the results. The multi-objective GMS model is superior than the benchmark model in producing the GMS schedule in terms of reliability, and violation objective functions with an average improvement between 2.68% and 92.44%. Friedman test using GRG metric shows significant better performance ($p\text{-values} < 0.05$) for PACS algorithm compared to benchmark algorithms. The proposed models and algorithm can be used to solve the multi-objective GMS problem while the new parameters' values can be used to obtain optimal or near optimal maintenance scheduling of generators. The proposed models and algorithm can be applied on different types of generating units to minimize the interruptions of energy and extend their lifespan.

Keywords: Sequential strategy, Generator maintenance, Unit commitment, Optimization, Graph model.

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List of Abbreviations

ACO	Ant Colony Optimization
ACS	Ant Colony System
AS	Ant System
ASrank	Rank-based Ant System
EAS	Elitist Ant System
GMS	Generator Maintenance Scheduling
GRA	Grey Relational Analysis
GRC	Grey Relational Coefficient
GRG	Grey Relational Grade
ISO	Independent System Operator
MMAS	Max-Min Ant System
MOPSO	Multi-objective Particle Swarm Optimization
MOSA	Multi-objective Simulated Annealing
NSGAII	Non-dominated Sorting Genetic Algorithm II
OEM	Original Equipment Manufacturer
PACS	Pareto Ant Colony System
S/N	Signal to Noise Ratio
SPEA2	Strength Pareto Evolutionary Algorithm 2
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

CHAPTER ONE
INTRODUCTION

1.1 Study Background

Sustainability of contemporary communities depends significantly on an efficient, safe and attainable electrical power supply (Eygelaar et al., 2018). Energy facilities have become an important resource in a nation's economy which, consequently, calls for efficient planning of the operation. This planning of operations is considered a highly challenging task especially for developing countries, due to the increasing demands for an electricity supply in those countries as a consequence of rapid development and economic demand. This imposed extra stress on the financial reserves of developing countries, as sources of cleaner energy, attracts high cost when compared to traditional methods of electricity generation (Eygelaar et al., 2018).

An essential element of operations and planning in power generation systems that makes a considerable impact on both economic and credibility aspects is Generator Maintenance Scheduling (GMS), which is considered a major economic issue in electric power systems (Lee et al., 2016). Scheduling is the process of allocating operations to time intervals on machines (Khoshnevi, 2000). Khoshnevi (2000) classifies scheduling into different types based on four parameters: job arrival patterns, number of machines in the shop, flow patterns in the shop, and the criteria by which the schedule is to be evaluated. There are different types of scheduling problems such as job-shop scheduling problem (Mohan et al., 2019), grid scheduling problem (Ankita & Sahana, 2022) , and GMS (Lindner et al., 2018).

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Appendix A

Dataset for the 26-unit test system

Units	C_i^{Fx}	C_i^{P}	C_i^{M}	P_i^{min}	P_i^{max}	oph_i^s	Up time	Down time	$\mathrm{Ini}_{\mathrm{hourS}}$
1	24.389	25.547	255470	2.4	12	1000	1	1	-1
2	24.411	25.675	256750	2.4	12	800	1	1	-1
3	24.638	25.803	258030	2.4	12	1200	1	1	-1
4	24.761	25.932	259320	2.4	12	1300	1	1	-1
5	24.888	26.061	260610	2.4	12	2100	1	1	-1
6	117.755	37.551	375510	4	20	100	1	1	-1
7	118.108	37.664	376640	4	20	1900	1	1	-1
8	118.458	37.777	377770	4	20	1900	1	1	-1
9	118.821	37.89	378900	4	20	800	1	1	-1
10	81.136	13.327	133270	15.2	76	540	3	2	3
11	81.298	13.354	133540	15.2	76	800	3	2	3
12	81.464	13.381	133810	15.2	76	3100	3	2	3
13	81.626	13.407	134070	15.2	76	2300	3	2	3
14	217.895	18	180000	25	500	200	4	2	-3
15	218.335	18.1	181000	25	100	600	4	2	-3
16	218.775	18.2	182000	25	100	1800	4	7	-3
17	142.735	10.694	106940	54.25	155	900	5	3	5
18	143.029	10.715	107150	54.25	155	1200	5	3	5
19	143.318	10.737	107370	54.25	155	300	5	3	5
20	143.597	10.758	107580	54.25	155	500	5	3	5
21	259.131	23	230000	68.95	197	2000	5	10	-4
22	259.649	23.1	231000	68.95	197	3450	5	4	-4
23	260.176	23.2	232000	68.95	197	1000	5	4	-4
24	177.058	10.862	108620	140	350	700	8	5	10
25	310.002	7.492	74920	100	400	500	8	5	10
26	311.91	7.503	75030	100	400	1450	8	5	10

Appendix B

Dataset for the 32-unit system

Units	C_i^{Fx}	C_i^{P}	C_i^{M}	P_i^{min}	P_i^{max}	oph_i^s	Up Time	Down Time	Ini_{hourS}
1	24.389	25.547	255470	2.4	12	1000	1	1	-1
2	24.411	25.675	256750	2.4	12	800	1	1	-1
3	24.638	25.803	258030	2.4	12	1200	1	1	-1
4	24.761	25.932	259320	2.4	12	1300	1	1	-1
5	24.888	26.061	260610	2.4	12	2100	1	1	-1
6	118.908	37.964	379640	4	20	100	1	1	-1
7	118.458	37.777	377770	4	20	1900	1	1	-1
8	118.908	37.964	379640	4	20	1900	1	1	-1
9	119.458	38.777	387770	4	20	800	1	1	-1
10	81.826	13.507	135070	15.2	76	540	3	2	3
11	81.136	13.327	133270	15.2	76	800	3	2	3
12	81.298	13.354	133540	15.2	76	3100	3	2	3
13	81.626	13.407	134070	15.2	76	2300	3	2	3
14	217.895	18	180000	25	100	200	4	2	5
15	219.775	18.6	186000	25	100	1000	4	2	5
16	218.335	18.1	181000	25	100	600	4	2	5
17	216.775	18.3	183000	25	100	2200	4	2	-3
18	218.775	18.2	182000	25	100	1800	4	2	-3
19	216.775	17.3	173000	25	100	1400	4	2	-3
20	142.735	10.737	107370	54.25	155	900	4	2	-3
21	143.029	10.715	107150	54.25	155	1200	5	3	5
22	143.318	10.737	107370	54.25	155	300	5	3	5
23	143.597	10.758	107580	54.25	155	500	5	3	5
24	259.131	23	230000	68.95	197	2000	5	4	-4
25	259.649	23.1	231000	68.95	197	3450	5	4	-4
26	260.176	23.2	232000	68.95	197	1000	5	4	-4
27	260.576	23.4	234000	68.95	197	100	5	4	-4
28	261.176	23.5	235000	68.95	197	540	5	4	-4
29	260.076	23.04	230400	68.95	197	900	5	4	-4
30	176.057	10.842	108420	140	350	700	8	5	10
31	310.002	7.492	74920	100	400	500	8	5	10
32	311.91	7.503	75030	100	400	1450	8	5	10

Appendix C

Dataset for the 36-unit system

Units	C_i^{Fx}	C_i^{P}	C_i^{M}	P_i^{min}	P_i^{max}	oph_i^s	Up Time	Down Time	Ini_{hourS}
1	24.38	25.5	24380	2.4	12	1000	1	1	-1
2	118.9	37.9	118900	4	20	800	1	1	-1
3	118.45	37.7	118450	4	20	1200	1	1	-1
4	118.9	37.9	118900	4	20	1300	1	1	-1
5	119.45	38.7	119450	4	20	2100	1	1	-1
6	117.75	37.5	117750	4	20	100	1	1	-1
7	118.1	37.66	118100	4	20	1900	1	1	-1
8	81.8	13.5	81800	15.2	76	1900	3	2	-1
9	81.13	13.32	81130	15.2	76	800	3	2	-1
10	81.29	13.35	81290	15.2	76	540	3	2	3
11	81.62	13.4	81620	15.2	76	800	3	2	3
12	217.89	18	217890	25	100	3100	4	2	3
13	219.77	18.6	219770	25	100	2300	4	2	3
14	218.33	18.1	218330	25	100	200	4	2	-3
15	216.77	18.2	216770	25	100	600	4	2	-3
16	218.77	18.2	218770	25	100	1800	4	2	-3
17	216.775	17.2	216775	25	100	900	4	2	5
18	218.775	19.2	218775	25	100	1200	4	2	5
19	143.02	10.71	143020	54.25	155	300	5	3	5
20	143.31	10.73	143310	54.25	155	500	5	3	5
21	143.59	10.75	143590	54.25	155	2000	5	3	-4
22	259.13	23	259130	68.95	197	3450	5	4	-4
23	259.64	23.1	259640	68.95	197	1000	5	4	-4
24	260.17	23.2	260170	68.95	197	700	5	4	10
25	260.57	23.4	260570	68.95	197	500	5	4	10
26	261.17	23.5	261170	68.95	197	1450	5	4	10
27	260.07	23.04	260070	68.95	197	1900	5	4	10
28	176.05	10.84	176050	140	350	800	8	5	10
29	177.05	10.86	177050	140	350	300	8	5	10
30	176.05	10.66	176050	140	350	500	8	5	10
31	177.95	10.96	177950	140	350	2000	8	5	10
32	310	7.49	310000	100	400	3450	8	5	10
33	311.9	7.5	311900	100	400	200	8	5	10
34	312.9	7.51	312900	100	400	600	8	5	10
35	314.9	7.53	314900	100	400	1800	8	5	10
36	313.9	7.61	313900	100	400	900	8	5	10

Appendix D

Dataset for the Load Demand with 26-unit system and 32-unit system

Periods	Hours	Weeks						
		Sunday (weekday)	Monday (weekday)	Tuesday (weekday)	Wednesday (weekday)	Thursday (weekday)	Friday (weekend)	Saturday (weekend)
Period (1)	12-1 am	1236	1533	1648	1648	1582	1804	1477
Period (1)	1-2 am	1162	1441	1550	1550	1488	1665	1364
Period (1)	2-3 am	1107	1373	1476	1476	1417	1572	1288
Period (1)	3-4 am	1089	1350	1451	1451	1393	1526	1250
Period (1)	4-5 am	1089	1350	1451	1451	1393	1480	1212
Period (1)	5-6 am	1107	1373	1476	1476	1417	1503	1231
Period (1)	6-7 am	1365	1693	1820	1820	1748	1526	1250
Period (1)	7-8 am	1587	1968	2116	2116	2031	1619	1326
Period (1)	8-9 am	1753	2173	2337	2337	2244	1850	1515
Period (1)	9-10 am	1771	2196	2362	2362	2267	2035	1667
Period (1)	10-11am	1771	2196	2362	2362	2267	2081	1705
Period (1)	11am-12 pm	1753	2173	2337	2337	2244	2104	1724
Period (1)	12-1 pm	1753	2173	2337	2337	2244	2081	1705
Period (1)	1-2 pm	1753	2173	2337	2337	2244	2035	1667
Period (1)	2-3 pm	1716	2128	2288	2288	2196	2012	1648
Period (1)	3-4 pm	1734	2151	2312	2312	2220	2012	1648
Period (1)	4-5 pm	1827	2265	2435	2435	2338	2104	1724
Period (1)	5-6 pm	1845	2288	2460	2460	2362	2312	1894
Period (1)	6-7 pm	1845	2288	2460	2460	2362	2289	1875
Period (1)	7-8 pm	1771	2196	2362	2362	2267	2243	1837
Period (1)	8-9 pm	1679	2082	2239	2239	2149	2174	1781
Period (1)	9-10 pm	1531	1899	2042	2042	1960	2127	1743
Period (1)	10-11 pm	1347	1670	1796	1796	1724	2012	1648
Period (1)	11pm-12am	1162	1441	1550	1550	1488	1873	1534
Period (2)	12-1 am	1291	1601	1722	1722	1653	1884	1544
Period (2)	1-2 am	1214	1506	1619	1619	1554	1739	1425
Period (2)	2-3 am	1157	1434	1542	1542	1480	1643	1346
Period (2)	3-4 am	1137	1410	1516	1516	1456	1594	1306

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Period (51)	7-8 pm	2052	2544	2736	2736	2627	2599	2129
Period (51)	8-9 pm	1945	2412	2594	2594	2490	2518	2063
Period (51)	9-10 pm	1774	2200	2366	2366	2271	2465	2019
Period (51)	10-11 pm	1560	1935	2081	2081	1997	2331	1909
Period (51)	11pm-12am	1347	1670	1796	1796	1724	2170	1778
Period (52)	12-1 am	1367	1695	1822	1822	1750	1994	1634
Period (52)	1-2 am	1285	1594	1714	1714	1645	1841	1508
Period (52)	2-3 am	1224	1518	1632	1632	1567	1739	1424
Period (52)	3-4 am	1204	1492	1605	1605	1541	1687	1382
Period (52)	4-5 am	1204	1492	1605	1605	1541	1636	1340
Period (52)	5-6 am	1224	1518	1632	1632	1567	1662	1361
Period (52)	6-7 am	1510	1872	2013	2013	1932	1687	1382
Period (52)	7-8 am	1754	2175	2339	2339	2246	1790	1466
Period (52)	8-9 am	1938	2403	2584	2584	2481	2045	1676
Period (52)	9-10 am	1958	2428	2611	2611	2507	2250	1843
Period (52)	10-11am	1958	2428	2611	2611	2507	2301	1885
Period (52)	11am-12 pm	1938	2403	2584	2584	2481	2327	1906
Period (52)	12-1 pm	1938	2403	2584	2584	2481	2301	1885
Period (52)	1-2 pm	1938	2403	2584	2584	2481	2250	1843
Period (52)	2-3 pm	1897	2353	2530	2530	2428	2224	1822
Period (52)	3-4 pm	1918	2378	2557	2557	2455	2224	1822
Period (52)	4-5 pm	2020	2504	2693	2693	2585	2327	1906
Period (52)	5-6 pm	2040	2530	2720	2720	2611	2557	2094
Period (52)	6-7 pm	2040	2530	2720	2720	2611	2531	2073
Period (52)	7-8 pm	1958	2428	2611	2611	2507	2480	2032
Period (52)	8-9 pm	1856	2302	2475	2475	2376	2403	1969
Period (52)	9-10 pm	1693	2100	2258	2258	2167	2352	1927
Period (52)	10-11 pm	1489	1847	1986	1986	1906	2224	1822
Period (52)	11pm-12am	1285	1594	1714	1714	1645	2071	1696

Appendix E

Dataset for the Load Demand with 36-unit system

Periods	Hours	Weeks						
		Sunday (weekday)	Monday (weekday)	Tuesday (weekday)	Wensday (weekday)	Thursday (weekday)	Friday (weekend)	Saturday (weekend)
Period (1)	12-1 am	2472	3066	3296	3296	3164	3608	2954
Period (1)	1-2 am	2324	2882	3100	3100	2976	3330	2728
Period (1)	2-3 am	2214	2746	2952	2952	2834	3144	2576
Period (1)	3-4 am	2178	2700	2902	2902	2786	3052	2500
Period (1)	4-5 am	2178	2700	2902	2902	2786	2960	2424
Period (1)	5-6 am	2214	2746	2952	2952	2834	3006	2462
Period (1)	6-7 am	2730	3386	3640	3640	3496	3052	2500
Period (1)	7-8 am	3174	3936	4232	4232	4062	3238	2652
Period (1)	8-9 am	3506	4346	4674	4674	4488	3700	3030
Period (1)	9-10 am	3542	4392	4724	4724	4534	4070	3334
Period (1)	10-11am	3542	4392	4724	4724	4534	4162	3410
Period (1)	11am-12 pm	3506	4346	4674	4674	4488	4208	3448
Period (1)	12-1 pm	3506	4346	4674	4674	4488	4162	3410
Period (1)	1-2 pm	3506	4346	4674	4674	4488	4070	3334
Period (1)	2-3 pm	3432	4256	4576	4576	4392	4024	3296
Period (1)	3-4 pm	3468	4302	4624	4624	4440	4024	3296
Period (1)	4-5 pm	3654	4530	4870	4870	4676	4208	3448
Period (1)	5-6 pm	3690	4576	4920	4920	4724	4624	3788
Period (1)	6-7 pm	3690	4576	4920	4920	4724	4578	3750
Period (1)	7-8 pm	3542	4392	4724	4724	4534	4486	3674
Period (1)	8-9 pm	3358	4164	4478	4478	4298	4348	3562
Period (1)	9-10 pm	3062	3798	4084	4084	3920	4254	3486
Period (1)	10-11 pm	2694	3340	3592	3592	3448	4024	3296
Period (1)	11pm-12am	2324	2882	3100	3100	2976	3746	3068
Period (2)	12-1 am	2582	3202	3444	3444	3306	3768	3088
Period (2)	1-2 am	2428	3012	3238	3238	3108	3478	2850
Period (2)	2-3 am	2314	2868	3084	3084	2960	3286	2692
Period (2)	3-4 am	2274	2820	3032	3032	2912	3188	2612
Period (2)	4-5 am	2274	2820	3032	3032	2912	3092	2532

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Period (51)	9-10 pm	3548	4400	4732	4732	4542	4930	4038
Period (51)	10-11 pm	3120	3870	4162	4162	3994	4662	3818
Period (51)	11pm-12am	2694	3340	3592	3592	3448	4340	3556
Period (52)	12-1 am	2734	3390	3644	3644	3500	3988	3268
Period (52)	1-2 am	2570	3188	3428	3428	3290	3682	3016
Period (52)	2-3 am	2448	3036	3264	3264	3134	3478	2848
Period (52)	3-4 am	2408	2984	3210	3210	3082	3374	2764
Period (52)	4-5 am	2408	2984	3210	3210	3082	3272	2680
Period (52)	5-6 am	2448	3036	3264	3264	3134	3324	2722
Period (52)	6-7 am	3020	3744	4026	4026	3864	3374	2764
Period (52)	7-8 am	3508	4350	4678	4678	4492	3580	2932
Period (52)	8-9 am	3876	4806	5168	5168	4962	4090	3352
Period (52)	9-10 am	3916	4856	5222	5222	5014	4500	3686
Period (52)	10-11am	3916	4856	5222	5222	5014	4602	3770
Period (52)	11am-12 pm	3876	4806	5168	5168	4962	4654	3812
Period (52)	12-1 pm	3876	4806	5168	5168	4962	4602	3770
Period (52)	1-2 pm	3876	4806	5168	5168	4962	4500	3686
Period (52)	2-3 pm	3794	4706	5060	5060	4856	4448	3644
Period (52)	3-4 pm	3836	4756	5114	5114	4910	4448	3644
Period (52)	4-5 pm	4040	5008	5386	5386	5170	4654	3812
Period (52)	5-6 pm	4080	5060	5440	5440	5222	5114	4188
Period (52)	6-7 pm	4080	5060	5440	5440	5222	5062	4146
Period (52)	7-8 pm	3916	4856	5222	5222	5014	4960	4064
Period (52)	8-9 pm	3712	4604	4950	4950	4752	4806	3938
Period (52)	9-10 pm	3386	4200	4516	4516	4334	4704	3854
Period (52)	10-11 pm	2978	3694	3972	3972	3812	4448	3644
Period (52)	11pm-12am	2570	3188	3428	3428	3290	4142	3392