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Generation scheduling analyses of the Slovenian power system in future

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Abstract The paper deals with a multi-objective power generation scheduling of the Slovenian power system in future. The year 2020 is selected for the analyses. A possible scenario of the power system composition is considered including an assumed scenario for electricity export. In the generation scheduling, three objective functions are analyzed: fuel cost, gaseous pollutant emissions and power generation unavailability. Two types of the genetic algorithm are used for optimization. The unit commitment and generation dispatch are solved as part of the power generation scheduling problem. The results show possible scenarios of power system operation and identify possible operational issues.

Keywords: multi-objective optimization, generation scheduling, power system, genetic algorithm, unavailability

Večkriterijska razporeditev obratovanja elektrarn: Elektroenergetski sistem Slovenije

Razvita je metoda za večkriterijsko optimalna razporeditev obratovanja elektrarn v slovenskem elektroenergetskem sistemu v prihodnosti v letu 2020. Eden od možnih scenarijev za sestavo elektroenergetskega sistema in izvoz električne energije je bil analiziran. V okviru metode optimalne razporeditve obratovanja elektrarn so upoštevani stroški goriva, količine izpustov snovi v okolje in nerazpoložljivost enot v elektrarnah. Časovno vključevanje enot in določitev njihovih moči obratovanja tekom dneva za pokrivanje dnevnega diagrama porabe predstavljata rešitev problema optimizacije. Rezultati kažejo, kako naj delujejo elektrarne, da bo ob čim manjših stroških in čim čistejšem okolju sistem zanesljivo deloval.

1 INTRODUCTION

The short-term generation scheduling of a power system is important for an economical and reliable delivery of the produced energy to the consumers. Therefore the power generation scheduling problem has an important role in power system operation and control.

The first step towards solving the generation scheduling problem is determining which units should be committed in a given time interval [1-3]. This problem is known as the unit commitment problem. The second step is finding the exact generation output of each committed unit such that the overall power output meets the load demand for a given time interval. This problem is known as generation dispatch problem [4, 5]. When solving any of these problems, usually a single objective is considered, primarily minimization of the operating cost. In the short-term generation scheduling, the operating cost comprises the fuel cost, start-up cost and shut-down cost. If only the operating cost is considered, the problem is, from the optimization point of view, a single-objective optimization problem. When more than one objective is considered, such as gaseous pollutant emissions and generation unavailability, the generation scheduling problem becomes a multi-objective optimization problem.

In this paper an improved hybrid genetic algorithm is used to optimize the unit commitment problem [6]. To solve the generation dispatch problem, an improved multi-objective genetic algorithm is applied [7].

The objective of the paper is to optimize the generation scheduling problem for the Slovenian power system in future. The system is based on a scenario that takes in consideration all the nuclear, fossil-fired and hydro-power plants scheduled to be in operation and connected to the transmission system by 2020. A detailed mathematical model of the unit commitment problem is developed. For the generation dispatch problem a multi-objective optimization model is used. The model considers three objectives: the fuel cost, the gaseous pollutant emissions and the power generation unavailability. The conventional generation scheduling problem and the combined economic-environmental-unavailability optimization problem are solved in separate case studies. The results are compared and analyzed.

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2 UNIT COMMITMENT MODEL

In this section, the unit commitment problem, as a substantial part of the generation scheduling problem is defined. The multi-objective generation dispatch problem is presented in detail in [4, 7, 8]. A short description of the unit commitment mathematical model [2, 6] is presented here.

2.1 Total operating cost objective function

The fuel cost, start-up cost and shut-down cost altogether comprise the total operating cost over the scheduling time period as follows:

$$F_T = \sum_{t=1}^{T}\sum_{i=1}^{N}[S_{i,t}F_{C_i}\left(P_{G_{i,t}}\right) + CU_i S_{i,t}\left(1\text{-}S_{i,t\text{-}1}\right) + CD_i S_{i,t}\left(1\text{-}S_{i,t+1}\right)] \quad (1)$$

where F_{C_i} is the fuel cost; $S_{i,t}$ is the on/off status of the i-th unit at the t-th hour; $S_{i,t} = 1$ when the unit is on; $S_{i,t} = 0$ when the unit is off; $P_{G_{i,t}}$is the power output of the i-th thermal unit at the t-th hour; $CU_i$is the start-up cost of the i-th unit; CD_i is the shut-down cost of the i-th unit; T is the total scheduling period; and N is the total number of units. In this study, the start-up cost and the shut-down cost are neglected, therefore the total cost is equal to the fuel cost.

2.2 Mathematical formulation

2.2.1 Single-objective optimization model

When the generation scheduling is solved as a single-objective optimization problem, the unit commitment is solved first by considering only the total operating cost:

$$Minimize\ [F_T(P_S)] \quad (2)$$

subject to:

$$g(P_S) = 0 \quad (3)$$
$$h(P_S) \leq 0 \quad (4)$$

where $g(P_S)$ and $h(P_S)$ are the equality and inequality problem constraints relevant for the unit commitment problem and P_S is the decision vector composed of ones and zeroes representing commitment or decommitment of a unit. It is a matrix where the number of the rows is equal to the number of the generating units and the number of the columns is equal to the number of the time intervals.

When the unit commitment is optimized, the fuel cost characteristics are only used to assess the on/off status of the available units in the system.

The matrix obtained with the unit commitment is then used to find the exact power outputs of the generating units committed for operation. This is done by optimizing the generation dispatch problem considering only the fuel cost objective. The obtained fuel cost is the one used in the further analysis.

2.2.2 Multi-objective optimization model

When the generation dispatch problem is optimized as a multi-objective problem considering the fuel cost, the gaseous pollutant emissions and the generation unavailability, the problem is mathematically formulated as:

$$Minimize\ [F_C(P_C),\ F_E(P_C),\ F_U(P_C)] \quad (5)$$

subject to:

$$g(P_C) = 0 \quad (6)$$
$$h(P_C) \leq 0 \quad (7)$$

where F_C is the fuel cost objective function, F_E is the gaseous pollutant emission objective function, F_U is the generation unavailability objective function, $g(P_C)$ and $h(P_C)$ are the equality and inequality constraints relevant for the generation dispatch problem, and P_C is a decision vector that represents one potential solution [7].

2.3 Constraints

Each constraint typical for the unit commitment [6] and generation dispatch problem [1, 4] is considered.

The transmission system is not considered to allow for simplification. However, power system losses are considered as percentage of the load demand. The losses of the Slovenian power system are assessed of 4.5 % of the total load demand including the export. This is somehow an optimistic value compared to the current losses in the transmission and distribution system which may both exceed 7%.

3 PROBLEM SOLUTION

An improved hybrid genetic algorithm (GA) is used to optimize the unit commitment problem [6]. An improved multi-objective genetic algorithm is applied to optimize the multi-objective generation dispatch problem [7].

GA is a heurism-based search algorithm which mimics the natural evolution law of selection and gene recombination in order to produce better offspring. The GA is proven to be an efficient and powerful method for obtaining new and better search points based on historical information [1, 9-13].

4 POWER SYSTEM DESCRIPTION

The Slovenian power system is consists of a nuclear, fossil-fired and hydro generating units. The total electricity generation share of the Krško nuclear power plant (NPP) on an annual level is some 40% of the total electricity generation. The fossil-fired and hydro-power plants participate with some 30% each. Electricity from the Krško NPP is supplied to Slovenia and Croatia [14].

The generation scheduling of the Slovenian power system is analyzed in [4].

In this paper the Slovenian future power system is analyzed. The operability data of each unit used in our analyses is taken from [15]. The year analyzed is 2020. Besides the existing Krško NPP, a new 1100 MW Krško NPP (JEK 2) is planned to be in operation by 2020 [15]. A new coal-fired unit at the Šoštanj thermal power plant (TPP) is to be operable by 2016, too. The system comprises also a new pumped-storage hydro-power plant (PSHP). The data about the generating units fuel cost, gaseous pollutant emissions, generation unavailability and hydraulic characteristics are given in [1].

5 ANALYSES AND RESULTS

A peak-load of 2434 MW was assumed in this study with the consideration of the assessed peak-loads for 2020 given in [15]. The used daily load curve considered this power as the peak-load of the assumption that the minimum load demand is 60% of the peak-load. The total electricity generation from the considered 2020 base-load and intermediate units is expected to be significantly higher than the assumed load demands, thus allowing for electricity export. The amount of electricity to be exported, including 348 MW reserved for Croatia, is determined as a difference between sum of the maximum power outputs of all the base-load units, all the intermediate-load units, the average hydro production and the peak-load demand. The power export during the day is foreseen to be varying in same manner as the load demands, and that it will be reduced during the low load demands hours.

Two case studies were developed and analyzed. In the first one, the generation scheduling was optimized as a single-objective optimization problem, i.e. the fuel cost objective is the only one considered. In the second one, the generation scheduling was optimized as a multi-objective optimization problem that includes three objectives: the cost objective, the pollutant emission objective and the generation unavailability objective.

5.1 *The first case study*

In the first case study, minimization of the fuel cost objective function for the Slovenian future power system was analyzed. The unit commitment problem was solved first. The margin selected for the spinning reserve was set at 10% of the load demand. The obtained unit commitment schedule was used as a reference point for the generation dispatch problem. The hourly generation scheduling of the thermal and the hydro units is given in Table 1 and Table 2, respectively.

Table 1: Hourly generation scheduling (MW) of all the thermal units operating in the Slovenian power system in future for the first case study

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Šoštanj TPP:																								
TEŠ PE1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TEŠ PE2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TEŠ B5	241	235	185	199	187	198	305	305	305	305	305	305	305	305	305	305	305	305	305	305	305	305	304	293
TEŠ B6	545	537	486	511	543	544	545	545	545	545	545	545	545	545	545	545	545	545	545	545	545	545	545	545
Trbovlje TPP:																								
TET B4	83	70	54	61	60	74	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	110	109	109
TET PPE	100	100	100	100	100	100	161	173	191	144	145	176	175	148	149	148	154	182	181	178	183	172	113	106
Brestanica TPP:																								
PB 4	0	0	0	0	0	0	0	0	0	0	0	0	0	56	0	0	0	66	65	65	67	0	0	0
PB 5	0	0	0	0	0	0	0	0	0	56	58	64	65	58	59	57	61	68	67	68	70	64	0	0
PB 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PE 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PE 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PE 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHPP Ljubljana:																								
B4 PPE1	0	0	0	0	0	0	0	0	0	104	104	104	104	104	104	104	104	104	104	104	104	104	0	0
B5 PPE2	0	0	0	0	0	0	0	0	104	104	104	104	104	104	104	104	104	104	104	104	104	104	100	0
Krško NPP	696	691	636	605	629	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696
JEK 2 NPP	1100	1080	1026	982	1037	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
Import:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total cost (F_C)=238179 ($)										Emission (F_E)=95 (ton)								Unavailability (F_U)=0.0721 (/)						

As seen from Table 1, the Krško NPP and JEK 2 are decreasing their power output during the hours of low load demands, i.e. performing the load following maneuvers. The load following is larger for the other base-load thermal generating units, such as Šoštanj B5 and B6.

Table 2: Hourly generation scheduling (MW) of all the hydro units operating in the Slovenian power system in future for the first case study

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Moste	2	2	2	2	2	2	10	12	13	5	7	10	10	4	6	6	5	11	11	13	13	12	3	2
Mavčiče	4	3	3	3	3	3	4	11	19	10	4	5	8	3	7	9	6	6	13	6	15	16	3	11
Medvode	13	9	10	11	13	9	10	6	3	7	13	5	12	6	12	6	5	10	6	3	6	10	11	12
Trbovlje	9	14	10	24	7	18	11	14	11	9	15	19	14	8	16	8	15	16	8	20	10	19	16	8
Vrhovo	18	7	11	9	11	20	11	9	11	6	16	10	9	20	15	16	9	12	14	13	9	14	14	15
Boštanj	11	11	17	14	12	10	16	12	13	8	8	11	8	19	16	16	8	17	8	18	10	14	18	11
Blanca	18	16	11	15	15	17	10	12	22	10	20	13	11	17	26	26	15	12	12	13	10	18	25	24
Krško	17	11	21	19	16	19	18	13	13	20	15	12	20	21	24	24	14	9	16	30	12	25	25	11
Brežice	9	9	9	9	9	9	23	43	43	11	17	20	12	29	11	26	33	26	30	30	43	27	20	9
Moste	12	19	14	26	11	19	15	17	14	10	13	27	15	13	24	34	4	20	11	23	13	17	14	18
Solkan	13	9	7	23	8	18	6	7	9	16	11	15	20	9	11	16	17	10	11	20	10	14	24	21
Doblar 1+2	26	38	43	28	17	55	31	28	73	31	35	21	33	28	26	38	23	31	29	50	31	26	31	36
Plave 1	15	17	14	23	21	17	12	25	18	13	22	19	15	23	25	13	17	11	30	31	15	26	23	29
Dravograd	15	19	21	11	23	10	12	24	13	22	19	12	18	16	17	18	18	12	20	17	21	20	21	18
Vuzenica	16	27	37	51	19	34	28	33	17	29	18	27	37	27	34	16	42	24	20	33	26	26	40	17
Vuhred	25	15	32	18	14	52	33	28	38	41	27	42	20	63	31	61	23	18	50	41	41	32	36	62
Ožbalt	39	21	22	17	52	32	33	26	44	60	29	33	18	50	40	43	39	29	27	28	30	34	43	68
Fala	36	19	18	34	35	33	26	43	45	27	24	33	28	26	24	32	40	25	27	24	35	47	31	33
M. Otok	14	12	42	24	12	40	18	31	63	39	23	19	47	34	33	14	27	48	17	59	26	38	14	31
Zlatoličje	50	61	82	69	77	87	76	51	49	49	54	54	39	106	49	82	57	54	50	106	87	49	124	71
Formin	24	24	24	24	24	24	44	119	119	77	28	61	45	30	76	105	70	62	90	91	119	112	76	72
Avče	-142	-143	-143	-140	-143	-143	-132	-69	0	101	104	86	142	116	168	130	127	32	119	50	-69	-101	-141	-143
Kozjak	-376	-376	-376	-376	-376	-376	-16	0	0	100	333	371	334	182	154	92	318	403	337	216	0	-209	-376	-376

Fig. 1 shows the total of the thermal and hydro generation compared to the total load demand, including consumption of the Avče PSHP and Kozjak PSHP, as well as the power export and transmission system power losses. The predicted load demand for an average day in the Slovenian future power system is shown, too.

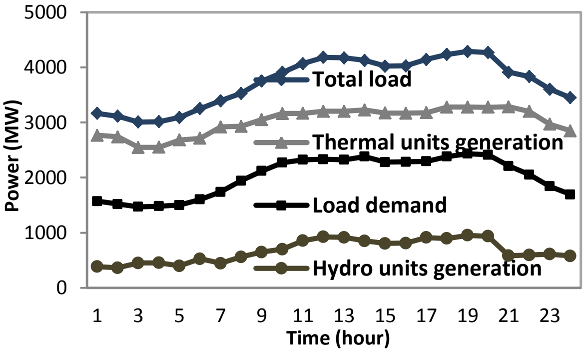

Figure 1. Load demand and power generation for the first case study.

Fig. 1 shows that the hydro-power generation mostly meets the peak-load demand. This is mainly the result of operation of the Avče PSHP and Kozjak PSHP, which generate during the high load demand hours. This hydro-power generation is considerable during the early hours of the day when the load demand is lower. This is related to the type of the hydro-power plants which already operate and those planned to operate in the Slovenian power system. Almost all of these plants represent a combination of two types of hydro-power plants: the run-of-the-river type and the accumulation type. They all share a common characteristic, i.e. a small net head and large water discharge through the turbine. Having much power stored for a longer period of time is limited by these characteristics. As the algorithm searches for the generation scheduling solutions assuring optimal power system efficiency, most of the hydro-power plants operate uninterruptedly during the entire day. This results in a most efficient exploitation of the water resources available to the system.

5.2 *The second case study*

The second case study addresses the combined economic-environmental-unavailability power dispatch problem. Contrary to the first case study, the unit commitment is not solved in advance due to the generation unavailability and gaseous pollutant emission objectives. Namely, higher reliability and higher emission efficiencies of the peak-load units are used compared to those of the base-load units.

The result of the multi-objective optimization problem solving is not just one optimal solution, but a set of them, none being better than the other considering all objectives. Such solutions are known as the Pareto optimal solutions and the front they describe is the so called Pareto optimal front. Usually, when the Pareto optimal front is defined, there is one solution which prioritizes all the objectives equally. This solution is known as the best compromise solution. The best compromise solution for the second case study, i.e. the generation scheduling of the thermal units and the hydro units is given in Table 3 and Table 4, respectively.

Table 3: Hourly generation scheduling (MW) of all the thermal units operating in the Slovenian power system in future for the second case study

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Šoštanj TPP:																								
TEŠ PE1	10	10	10	10	10	10	10	11	12	12	12	13	14	13	12	13	13	15	15	15	13	11	10	10
TEŠ PE2	10	10	10	10	10	10	11	11	12	12	12	13	14	13	12	13	13	15	15	15	12	11	10	10
TEŠ B5	170	173	155	162	173	177	183	185	190	192	191	196	200	195	192	194	194	201	203	201	194	184	183	178
TEŠ B6	500	500	500	500	500	502	545	545	545	545	545	545	545	545	545	545	545	545	545	545	545	545	545	502
Trbovlje TPP:																								
TET B4	50	53	45	47	51	57	87	95	104	107	108	110	110	109	108	109	109	110	110	110	110	97	70	58
TET PPE	100	100	100	100	100	100	100	100	101	100	102	109	112	104	102	103	104	118	124	117	104	100	100	100
Brestanica TPP:																								
PB 4	30	30	30	30	30	30	34	36	39	40	40	43	45	41	41	41	42	47	48	46	41	37	30	30
PB 5	30	30	30	30	30	30	35	38	40	41	42	44	46	43	42	44	43	48	49	47	42	38	30	30
PB 6	16	16	14	15	15	17	23	26	27	28	28	30	31	29	29	29	29	32	33	32	29	26	20	18
PE 7	16	16	14	14	15	17	23	26	28	28	29	30	31	29	29	29	29	32	34	32	29	26	20	18
PE 8	16	17	14	14	16	17	23	26	27	28	28	30	31	30	29	29	29	32	34	32	29	26	20	18
PE 9	16	16	14	14	15	17	23	26	27	28	28	30	31	29	29	29	30	32	33	32	29	26	20	18
CHPP Ljubljana:																								
B4 PPE1	45	47	39	39	45	50	73	80	86	90	90	94	98	93	91	92	93	100	103	100	92	81	60	52
B5 PPE2	46	48	41	42	47	52	76	83	89	92	93	97	101	95	94	94	95	103	104	102	95	84	62	53
Krško NPP	696	674	663	686	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696	696
JEK 2	1100	1034	1025	988	1043	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
Import:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fuel cost (F_C)=239507 ($) Emission ($F_E$)=17.5 (ton) Unavailability (F_U)=0.0701 (/)

Table 4: Hourly generation scheduling (MW) of all hydro units operating in the Slovenian power system in future for the second case study

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Moste	2	2	2	2	2	2	2	12	13	4	9	13	13	7	10	8	5	13	13	13	13	3	2	2
Mavčiče	3	3	3	3	3	3	3	7	16	7	4	6	9	13	4	5	5	13	23	20	8	5	7	3
Medvode	12	10	9	11	8	14	9	8	4	10	8	8	14	5	10	7	8	7	4	3	7	4	5	20
Trbovlje	10	13	12	12	12	15	10	12	14	14	15	14	8	19	13	11	10	11	12	25	8	13	26	8
Vrhovo	10	17	8	11	8	17	12	9	12	17	11	10	8	11	21	16	10	13	8	16	10	13	22	12
Boštanj	16	9	10	10	12	12	13	13	7	9	13	17	8	19	10	17	13	18	8	23	8	8	16	14
Blanca	16	14	9	8	14	21	17	10	14	21	11	18	11	24	23	22	13	23	17	10	16	13	22	10
Krško	13	20	20	17	16	15	17	13	14	13	17	13	12	18	33	20	11	12	11	13	33	16	22	13
Brežice	9	9	9	9	9	9	9	14	30	22	9	10	34	16	32	23	21	28	43	43	43	34	13	10
Moste	22	13	13	11	17	16	20	6	14	25	14	20	8	12	22	18	20	10	12	10	9	22	25	26
Solkan	14	14	11	11	13	13	11	16	10	11	8	10	14	16	14	23	15	17	14	7	11	8	20	24
Doblar 1+2	42	16	16	16	16	17	19	18	29	23	33	22	73	35	50	32	21	73	73	56	49	18	43	17
Plave 1	14	27	28	19	17	19	23	19	14	24	17	16	16	20	25	18	21	10	18	17	16	25	31	18
Dravograd	16	14	15	24	10	20	15	25	7	24	19	17	10	15	17	25	18	10	26	15	13	13	24	23
Vuzenica	17	30	21	18	36	36	27	17	19	29	48	20	13	38	62	27	15	51	25	15	17	29	28	38
Vuhred	31	24	24	21	23	35	25	25	40	60	44	24	19	26	50	77	20	24	22	38	70	29	72	19
Ožbalt	22	48	31	32	23	48	44	22	34	66	36	29	27	19	36	75	31	18	27	28	75	54	34	20
Fala	24	32	26	36	28	30	38	26	22	33	29	45	28	30	30	31	48	24	29	23	18	32	41	41
M. Otok	12	12	18	45	28	31	19	27	31	61	26	25	22	20	60	57	37	28	35	23	39	23	33	12
Zlatoličje	59	69	78	75	70	67	52	32	35	65	74	63	47	45	57	81	46	29	50	79	72	102	139	137
Formin	24	24	24	24	24	24	24	64	116	40	39	37	119	49	90	72	72	120	120	118	119	77	38	80
Avče	-143	-143	-143	-143	-143	-143	-141	-94	0	155	168	170	11	168	153	164	167	9	7	1	0	-132	-143	-143
Kozjak	-376	-376	-376	-376	-376	-376	-240	0	0	0	237	354	404	302	16	0	312	404	404	404	0	0	-373	-375

In the second case study, most of the units, considered as the peak-load units operate and generate during the hours of the scheduled time period. Most of the thermal units operate as intermediate units, thus performing the load following maneuvers during the day. This is the result of the emission and reliability competitiveness between the peak-load units and the largest coal-fired units. Also, it is evident that the combined-cycle gas units, such as the Trbovlje TPP – PPE and the Ljubljana combined heat and power plants (CHPP) - B4 and B5 are with significantly increased power outputs compared to the first case study. Besides being emission competitive, the fuel cost of these units is only slightly larger than that of the coal-fired generating units.

The Pareto optimal front for the Slovenian power system in future obtained in the second case study is shown in Fig. 2. The figure depicts projections of each solution on each of the three planes representing the optimal function values. To explore the Pareto front, a set of 43 user-supplied weights were applied.

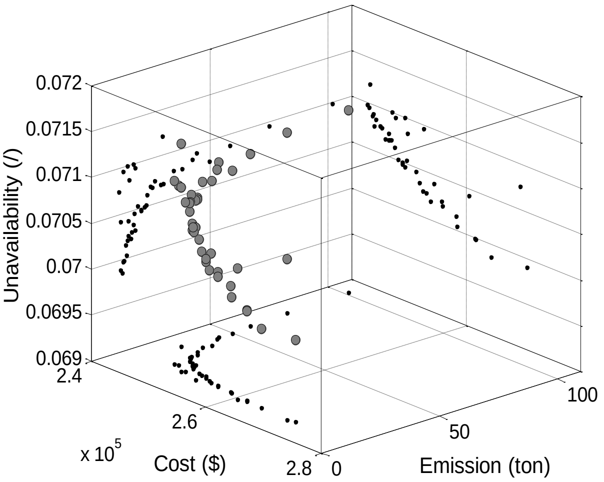

Figure 2. Pareto optimal front obtained in the second case study

5.3 Comparison and comments

Table 5 shows a comparison between the optimal solutions obtained in the first case study, where only the fuel cost objective is considered, and the best compromise solution from the second case study, where all the three objectives are considered.

Table 5: Comparison of the results

	Cost objective	**All objectives**	**Rel. difference [%]**
Fuel cost ($)	238179	239507	**0.55**
Emission (ton)	95	17.5	**-81.58**
Unavailability (/)	0.0721	0.0701	**-2.77**

The last column of Table 5 shows that considering the environmental objective in the optimization process as another function to be minimized can significantly reduce the gaseous pollutant emissions in the environment. This will increase the generation cost by nearly half a percent. Table 5 shows that the generation unavailability is reduced as well. The obtained values for the cost, gaseous pollutant emissions and generation unavailability are obtained using generic data. The actual values may differ significantly.

The results show that load following of the largest TPPs, including the NPPs is likely to occur in a power system with a dominant generation from nuclear sources such as the Slovenian future power system. The load following with NPPs is of substantial importance for flexible operation of the power system. This may be of special significance for a power system under deregulated electricity market and a power system with an increased penetration of renewable power sources. However, the load following with NPPs may significantly decrease their annual power production which in turn may result with prolonged return of the investment. The load following with NPP may have safety implications. Therefore, additional safety analyses are required.

6 CONCLUSIONS

The generation scheduling of the Slovenian future power system is the main topic of this paper. The system composition is based on the development strategy for the Slovenian power system between the years 2011 and 2020, with the year 2020 selected for the analyses. The analyzed power system has two nuclear power plants, which are the dominant source of electricity.

The multi-objective optimization generation scheduling problem is solved for the presented power system. Both the unit commitment and the generation dispatch are solved. Three objective functions are taken into account: fuel cost, gaseous pollutant emissions and power generation unavailability. Two types of the genetic algorithm are used for optimization. A comparison is made between the optimal solution obtained with a single-objective optimization, considering only the fuel cost, and the best compromise solution obtained with a multi-objective optimization. The results show that the optimal scheduling of power generation in the power system improves the pollutant emissions prevention efficiency of the system and decreases the power generation unavailability. The results show the necessity of having load following with nuclear power plants in the analyzed Slovenian future power system.

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