IDENTIFYING EFFICIENT PUMP COMBINATIONS IN WATER DISTRIBUTION NETWORKS

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SUMMARY

Energy costs regarding pumping discharge lines constitute the most important item in the budget of the water utilities in relation to municipal water distribution networks. Selection of the efficient pump combination during operation might reduce energy costs. For the correct choice of pump selection, characteristics of the transmission lines and network pipes, actual pump performance curves, daily demand curve should be known for defining the task. The definition of the task denotes the increase of the storage tank of the system from a given level to a certain level during a specific period of the day. Different examples were worked out using SCADA data using geographic information systems (GIS). It was found out that efficient pump combinations reduces energy costs considerably. The magnitude of the savings varies 5%-10% depending on the case studied.

INTRODUCTION

Energy costs regarding pumping discharge lines constitute the most important item in the budget of the water utilities in relation to municipal water distribution networks. Selection of the efficient pump combination during operation might reduce energy costs. For the correct choice of pump selection, characteristics of the transmission lines and network pipes, actual pump performance curves, daily demand curve should be known for the defined task. The definition of the task denotes the increase of the storage tank of the system from a given level to a certain level during a specific period of the day. Basic pump performance curves are head-discharge and efficiency curves. There are various algorithms in the literaure for the efficient pump selection regarding the determination of the operation policies; this study puts in practice Ormsbee and Walski (1989) and Chase and Ormsbee (1993) algorithms using geographic information systems (GIS) concerning real time applications of a two-pressure zone region with multi storage tanks. The case study area was located within the water distribution network of Ankara, Turkey.

METHODOLOGY

First Step. The required amount of water, Q_{req}, during pumping period, T, is determined based on the defined the task. It consists of basically two parts; one is the amount of water, increasing the level of the storage tank(s) from the initial level of H_i to the final level of H_f, the other is the required water, satisfying the consumers' demands during T:

$$Q_{req} = Q_{use} + (1/T) * \sum_{1}^{N} A_{tank}(k) * [H_f(k) - H_i(k)] \qquad (1)$$

where N, is the number of tanks; k, is the pump in operation; A_{tank}, is the surface area of the tank; T, is the pumping period; Q_{use} is the flow of water used by the consumers during T. Both recent demand curve of the pressure zone and actual SCADA readings were employed concerning the determination of Q_{use}.

Second Step. The number of all the pump combinations are determined; for each combination the network is solved by using a hydraulic network solver where each tank level

is taken as equal to the initial level. The solution of each pump combination provides pump discharge values either above or below the the required discharge Q_{req}. At a given combination, pumps discharging above Q_{req} are called all together, Q_a ($Q_a > Q_{req}$) whereas pumps discharging below Q_{req} are called all together,
Q_b ($Q_b < Q_{req}$). In order to accomplish the task within the given period, the pumps discharging all together Q_a, should run shorter than the pumps discharging all
together Q_b.

Third Step. Both Q_a and Q_b vary as a function of time because of the varying tank levels. In order to take into account this fact an iterative method is applied; average values of Q_a and Q_b are calculated succesively based on different durations of $f_a * T$ and $f_b * T$ where f_a and f_b add to unity using extended period simulation option of the hydraulic network solver. At a particular combination of f_a and f_b, Q_{req} is satisfied:

$$Q_{req} = f_a * \bar{Q}_a + f_b * \bar{Q}_b \quad (2)$$

Fourth Step. The energy required for satisfying Q_{req}, is determined based on the operation of pumps discharging both above and below Q_{req}:

$$P = (\gamma * Q_p * H_p) / e \quad (3)$$

$$E = \sum_{1}^{T/\Delta t} P_i * \Delta t \quad (4)$$

where P is power, γ is specific weight of water, Q_p is water discharged through the pump, H_p is head produced by the pump, e is the efficiency of the operating point of the related pump, E is the energy required, Δt is the period of the considered operation during extended period simulation.

Fifth Step. The cost for each alternative will then be calculated by using unit price of electricity. The lowest cost will be recommended as the most efficient pump combination. For each alternative, each pump operation both above and below Q_{req} will be taken into account by evaluating each time increment during operation.

The network was modeled using the system characteristics gathered from the water utility of Ankara. The methodology described above has been coded into a computer program which combines all the network data implemented in a GIS environment, SCADA recordings, a hydraulic network solver and the above mentioned algorithm.

CASE STUDY

The already defined algorithm was applied to a two- pressure zone region with multi storage tanks; the case study area was located within the water distribution network of Ankara, Turkey. The pressure zones N7 and N8 were located at the northern part of Ankara; the total population is approximately 85 000; these pressure zones are the most upstream pressure zones on the North transmission line of Ankara. There are three parallely connected pumps at each of the pumping stations. Each storage tank has a capacity of 5000 m^3 . SCADA recordings contain the discharge data of the water pumped to the pressure zone(s).

One Pressure Zone

First studied case dates from 21-22 July 1997. The defined task is to increase the tank level from 1155.09 m to 1157.38 m during 16 hours between 17:00 on July and 09:00 on July 22 (N8 pressur zone); the average water demand was equal to 37.08 lt/s. According to the defined task, following result was obtained (Table 1). The combination numbered “6” was used in actual application by the operator; however, the combination numbered “20” was indicated by the proposed methodology as the least cost alternative which allows 4.53% saving.

Table 1. Result of the Case Study on 21-22 July 1997

Operating	**Combinations**		$\overline{Q}_a$	$\overline{Q}_b$	f_a	f_b	$\overline{E}_a$	$\overline{E}_b$	**Cost**		**Tank**
Option	**1. Group**	**2. Group**	**(lt/s)**	**(lt/s)**	**(%)**	**(%)**	**(kWhr/m^3)**	**(kWhr/m^3)**	**T.L./Dur.**	**T.L./m^3**	**Elev. (m)**
1	P1+P2	None	82.09	0.00	83	17	0.1644	0.0000	51,935,403	5,796	1157.38
2	P1+P2	P1	82.76	43.71	62	38	0.1633	0.1655	51,585,895	5,757	1157.38
3	P1+P2	P2	82.61	38.36	67	33	0.1635	0.1635	51,556,041	5,753	1157.38
4	P1+P2	P3	82.70	42.32	64	36	0.1634	0.1645	51,708,163	5,770	1157.38
5	P1+P3	None	85.68	0.00	79	21	0.1654	0.0000	51,906,676	5,793	1157.38
6	*P1+P3*	*P1*	*86.54*	*43.71*	*57*	*43*	*0.1643*	*0.1655*	***51,988,280***	*5,802*	*1157.38*
7	P1+P3	P2	86.35	38.35	62	38	0.1645	0.1635	51,881,468	5,790	1157.38
8	P1+P3	P3	86.50	42.35	58	42	0.1643	0.1644	51,778,428	5,778	1157.38
9	P2+P3	None	80.90	0.00	84	16	0.1636	0.0000	51,521,587	5,750	1157.38
10	P2+P3	P1	81.56	43.71	64	36	0.1625	0.1655	51,389,406	5,735	1157.38
11	P2+P3	P2	81.40	38.35	69	31	0.1627	0.1635	51,383,679	5,734	1157.38
12	P2+P3	P3	81.50	42.32	66	34	0.1626	0.1645	51,510,731	5,748	1157.38
13	P1+P2+P3	None	118.17	0.00	58	42	0.1709	0.0000	54,262,428	6,056	1157.38
14	P1+P2+P3	P1	120.93	43.75	32	68	0.1680	0.1654	52,955,361	5,910	1157.38
15	P1+P2+P3	P2	120.51	38.37	36	64	0.1684	0.1634	52,486,092	5,857	1157.38
16	P1+P2+P3	P3	120.82	42.38	33	67	0.1681	0.1643	52,712,067	5,883	1157.38
17	None	P1+P2	84.69	0.00	80	20	0.1598	0.0000	50,200,260	5,602	1157.38
18	None	P1+P3	89.11	0.00	76	24	0.1607	0.0000	50,456,181	5,631	1157.38
19	None	P2+P3	83.53	0.00	81	19	0.1592	0.0000	49,936,473	5,573	1157.38
20	*None*	*P1+P2+P3*	*129.70*	*0.00*	*52*	*48*	*0.1588*	*0.0000*	***49,634,460***	*5,539*	*1157.38*
21	P1	P1+P2	82.40	45.64	60	40	0.1640	0.1597	51,100,549	5,703	1157.38
22	P1	P1+P3	86.06	45.62	55	45	0.1650	0.1598	51,409,278	5,737	1157.38
23	P1	P2+P3	81.20	45.64	62	38	0.1631	0.1597	50,919,838	5,682	1157.38
24	P1	P1+P2+P3	119.79	45.56	30	70	0.1693	0.1600	51,859,986	5,787	1157.38
25	P2	P1+P2	82.55	40.20	65	35	0.1637	0.1552	50,843,087	5,674	1157.38
26	P2	P1+P3	86.26	40.20	60	40	0.1647	0.1552	51,087,209	5,701	1157.38
27	P2	P2+P3	81.36	40.19	67	33	0.1629	0.1552	50,702,810	5,658	1157.38
28	P2	P1+P2+P3	120.31	40.19	34	66	0.1687	0.1553	51,103,562	5,703	1157.38
29	P3	P1+P2	82.43	44.60	61	39	0.1639	0.1584	50,982,950	5,690	1157.38
30	P3	P1+P3	86.10	44.59	56	44	0.1649	0.1584	51,275,234	5,722	1157.38
31	P3	P2+P3	81.24	44.61	63	37	0.1631	0.1584	50,811,692	5,670	1157.38
32	P3	P1+P2+P3	119.96	44.53	30	70	0.1691	0.1586	51,140,822	5,707	1157.38

In addition to the real case example, a synthetic scenario was generated: the pressure at the suction side was assumed to be decreased by ten meters. The defined task is to increase the tank level from 1154.00 m to 1155.00 during seven hours between 20:00 and 03:00 where the average water demand is equal to 15 lt/sec. According to the defined task, following result was obtained (Table 2). The least cost combination is numbered as “18”. Compared with other combinations, it is noted that at most 14.7% and at least 1% saving could be achieved.

Table 2. Result of the Synthetic Case with Low Entrance Pressure

Operating Option	Combinations 1. Group	2. Group	$\overline{Q_a}$ (lt/s)	$\overline{Q_b}$ (lt/s)	f_a (%)	f_b (%)	$\overline{E_a}$ (kWhr/m^3)	$\overline{E_b}$ (kWhr/m^3)	Cost T.L./Dur.	T.L./m^3	Tank Elev. (m)
1	P1+P2	None	55.21	0.00	82	18	0.2117	0.0000	19,424,754	7,363	1155.00
2	P1+P2	P1	56.52	31.55	56	44	0.2087	0.1997	19,019,109	7,209	1155.00
3	P1+P2	P2	56.03	25.17	66	34	0.2098	0.2189	19,530,804	7,403	1155.00
4	P1+P2	P3	56.32	29.19	60	40	0.2092	0.2050	19,187,831	7,273	1155.00
5	P1+P3	None	58.96	0.00	77	23	0.2058	0.0000	18,940,123	7,179	1155.00
6	P1+P3	P1	60.14	31.60	49	51	0.2034	0.1995	18,680,623	7,081	1155.00
7	P1+P3	P2	59.73	25.21	59	41	0.2042	0.2187	19,180,178	7,270	1155.00
8	P1+P3	P3	59.98	29.22	53	47	0.2037	0.2049	18,843,337	7,143	1155.00
9	P2+P3	None	53.36	0.00	85	15	0.2141	0.0000	19,674,738	7,458	1155.00
10	P2+P3	P1	54.45	31.52	61	39	0.2113	0.1998	19,213,975	7,283	1155.00
11	P2+P3	P2	54.05	25.16	70	30	0.2123	0.2189	19,637,490	7,444	1155.00
12	P2+P3	P3	54.28	29.15	65	35	0.2117	0.2052	19,393,050	7,351	1155.00
13	P1+P2+P3	None	70.93	0.00	64	36	0.2292	0.0000	21,027,543	7,971	1155.00
14	P1+P2+P3	P1	77.96	31.73	30	70	0.2195	0.1991	19,380,922	7,347	1155.00
15	P1+P2+P3	P2	76.58	25.37	39	61	0.2221	0.2178	20,279,162	7,687	1155.00
16	P1+P2+P3	P3	77.36	29.33	34	66	0.2206	0.2045	19,791,040	7,502	1155.00
17	None	P1+P2	60.21	0.00	76	24	0.2013	0.0000	18,674,399	7,079	1155.00
18	*None*	*P1+P3*	*63.77*	*0.00*	*72*	*28*	*0.1969*	*0.0000*	***18,334,885***	*6,950*	*1155.00*
19	None	P2+P3	57.78	0.00	79	21	0.2039	0.0000	18,871,820	7,154	1155.00
20	None	P1+P2+P3	91.39	0.00	50	50	0.2000	0.0000	18,524,239	7,022	1155.00
21	P1	P1+P2	54.68	33.43	59	41	0.2128	0.1937	19,307,281	7,319	1155.00

Multiple Zone

On Figure 1, a multiple zone with three separate zones is given. According to multiple zone model, first the pump combinations of zone A and zone B have to be identified in order to determine the discharge required at zone C for the predefined task period. Therefore, if a task were defined for zone C, also zone A and zone B have to be solved by the computer program in advance separately for the time period described at the task of zone C. While solving the upper zones, no new tasks were defined related with tank elevations but in fact required demand is taken into consideration for these zones regarding the duration of the time interval defined for zone C.

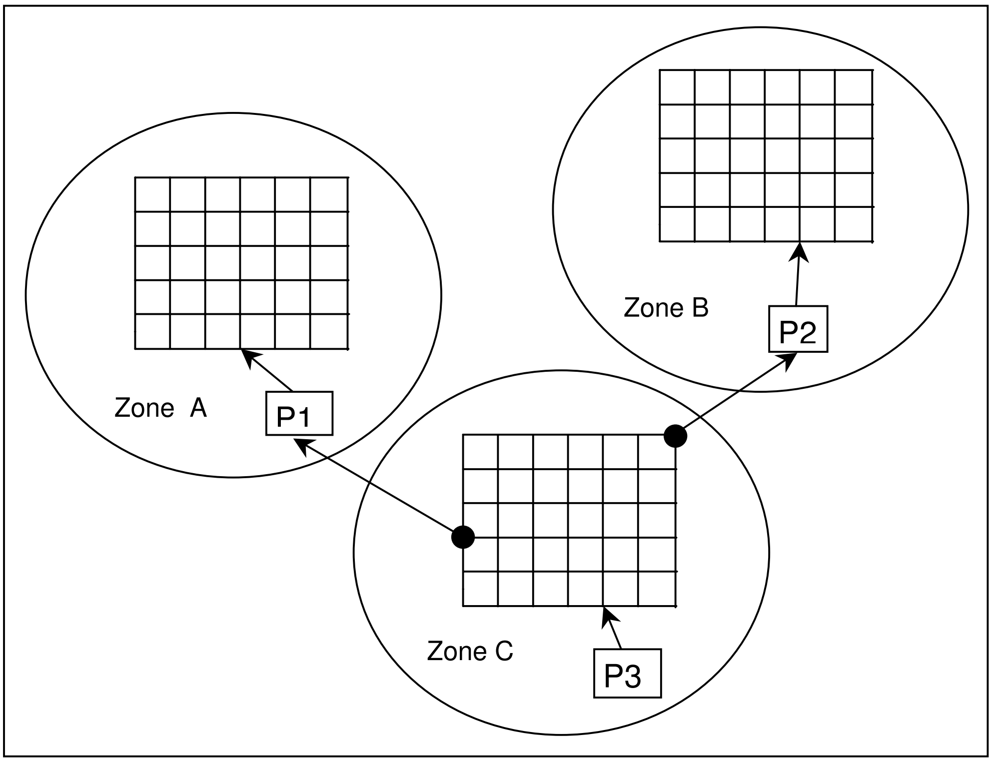

Figure 5.1. Multiple zone configuration

Finding the required pump discharge for P1 and P2 pump stations, the combined discharge file is then created in order to use it for zone C's input file. Demand values for upper zones have to be attached to the nodes, which connects the zone C to other zones. Unlike the single zone case, this model will include all pumps at the various pumping stations. Using current pump status at the other pump stations, simulation will be conducted to determine the hydraulic impact of placing the proposed pump groups into service. In the multi zones study, the subject of this study was progressed through N7 zone, which is connected to N8 sub pressure zones. In this part of the study, studied system became more complicated by including other storage tanks and pump stations at N7 zone.

The real case example dates from 23 May 2001. The defined task is to increase the tank level at N7 zone from 1113.15 m to 1114.58 m during 2.5 hours between 00:30 and 03:00, where the average water demand is equal to 42.02 lt/s.

According to the suggested method for multi zone systems, first N8 zone, which is the upper zone of N7, was solved without defining a particular task for this zone but considering the required demand in the zone for the duration of the time interval defined for zone N7. First of all, the upper zone, N8 was solved (Table 3).

Table 3. Result of the Case Study on 23 May for N8 zone

Oper. Opt.	Combinations 1. Group	2. Group	$\overline{Q_a}$ (lt/s)	$\overline{Q_b}$ (lt/s)	f_a (%)	f_b (%)	$\overline{E_a}$ (kWhr/m^3)	$\overline{E_b}$ (kWhr/m^3)	Cost (TL/Dur)	Cost (TL/m^3)	T53 Elev.(m)
1	P1+P2+P3	None	45.93	0.00	40	60	0.1561	0.0000	2,078,080	18,200	1155.48
2	*P1+P2+P3*	*P1*	*39.37*	*0.00*	*40*	*60*	*0.1515*	*0.0000*	***1,728,603***	*15,140*	*1155.45*
3	P1+P2+P3	P2	44.36	0.00	40	60	0.1543	0.0000	1,983,195	17,369	1155.47
4	P1+P2+P3	P3	84.53	0.00	40	60	0.1557	0.0000	3,812,870	33,394	1155.66
5	P1+P2+P3	P1+P2	89.30	0.00	40	60	0.1569	0.0000	4,059,422	35,553	1155.68
6	P1+P2+P3	P1+P3	82.91	0.00	40	60	0.1546	0.0000	3,714,652	32,534	1155.65
7	P1+P2+P3	P2+P3	126.33	0.00	40	60	0.1582	0.0000	5,792,183	50,729	1155.85
8	None	P1+P2+P3	46.00	0.00	20	80	0.1559	0.0000	1,039,233	9,102	1155.40
9	P1	P1+P2+P3	39.43	0.00	20	80	0.1512	0.0000	863,955	7,567	1155.38
10	P2	P1+P2+P3	44.44	0.00	20	80	0.1540	0.0000	991,859	8,687	1155.39
11	P3	P1+P2+P3	84.64	0.00	20	80	0.1554	0.0000	1,906,067	16,694	1155.49
12	P1+P2	P1+P2+P3	89.44	0.00	20	80	0.1566	0.0000	2,029,937	17,779	1155.50
13	P1+P3	P1+P2+P3	83.04	0.00	20	80	0.1543	0.0000	1,857,005	16,264	1155.48
14	P2+P3	P1+P2+P3	126.53	0.00	20	80	0.1580	0.0000	2,896,427	25,368	1155.58

At the beginning of the time period at 00:30 the tank level at T53 was 1155.41 m. Considering both the ending tank levels and the total costs of the combinations second one was selected, because its ending level is slightly higher and near to the beginning level and its cost is relatively lower when compared to the others. When the combination "3", which was used in real application by the operator, was compared with this combination "2", it was noticed that approximately 14.73 % saving could be achieved. Second, the obtained pump discharge values from the selected combination were attached to the link node at N7 zone, which connects N8 zone to the N7 zone. The demand values for that node are presented on Table 4. Then, N7 zone was solved according to the pre-described task with the first option of the computer program considering required demand and the tank levels. According to this option, the following result was obtained for N7 zone (Table 5).

Table 4. Demand Values for the Connection Node at N7 zone on 23 May

Time	Demand (lt/s)
00:30:00	0
01:00:00	0
01:30:00	0
02:00:00	39.38
02:30:00	39.35

Table 5. Result of the Case Study for N7 zone on May 23

Oper.	Combinations		$\overline{Q}_a$	$\overline{Q}_b$	f_a	f_b	$\overline{E}_a$	$\overline{E}_b$	Cost		T34
Opt.	1. Group	2. Group	(lt/s)	(lt/s)	(%)	(%)	(kWhr/m^3)	(kWhr/m^3)	(TL/Dur)	(TL/m^3)	Elev.(m)
1	P1+P2	None	280.6	0.0	72	28	0.2110	0.0000	30,704,530	16,984	1114.58
2	P1+P2	P1	279.5	175.2	25	75	0.2117	0.1664	26,478,332	14,646	1114.58
3	P1+P2	P2	279.5	182.3	19	81	0.2117	0.1653	25,855,291	14,302	1114.58
4	P1+P2	P3	279.5	176.5	24	76	0.2117	0.1662	26,365,795	14,584	1114.58
5	P1+P3	None	280.0	0.0	72	28	0.2110	0.0000	30,711,430	16,988	1114.58
6	P1+P3	P1	279.0	175.2	25	75	0.2118	0.1664	26,486,225	14,651	1114.58
7	P1+P3	P2	279.0	182.3	19	81	0.2118	0.1653	25,862,692	14,306	1114.58
8	P1+P3	P3	279.0	176.5	24	76	0.2118	0.1662	26,374,885	14,589	1114.58
9	P2+P3	None	284.1	0.0	71	29	0.2107	0.0000	30,666,108	16,963	1114.58
10	P2+P3	P1	283.1	175.2	24	76	0.2115	0.1664	26,426,774	14,618	1114.58
11	*P2+P3*	*P2*	*283.1*	*182.2*	*19*	*81*	*0.2115*	*0.1653*	***25,814,305***	*14,279*	*1114.58*
12	P2+P3	P3	283.1	176.5	23	77	0.2115	0.1662	26,315,201	14,556	1114.58
13	P1+P2+P3	None	334.0	0.0	60	40	0.2619	0.0000	38,106,706	21,079	1114.58
14	P1+P2+P3	P1	332.7	174.4	17	83	0.2628	0.1672	28,188,722	15,593	1114.58
15	P1+P2+P3	P2	332.7	181.5	13	87	0.2628	0.1660	27,162,085	15,025	1114.58
16	P1+P2+P3	P3	332.7	175.9	16	84	0.2628	0.1669	27,986,652	15,481	1114.58
17	None	P1+P2	289.1	0.0	71	29	0.2052	0.0000	30,532,418	16,889	1114.58
18	None	P1+P3	288.1	0.0	71	29	0.2052	0.0000	30,540,359	16,893	1114.58
19	None	P2+P3	292.4	0.0	70	30	0.2050	0.0000	30,506,952	16,875	1114.58
20	None	P1+P2+P3	354.2	0.0	58	42	0.2483	0.0000	36,960,142	20,444	1114.58
21	P1	P1+P2	289.5	175.8	26	74	0.2049	0.1658	26,809,010	14,829	1114.58
22	P1	P1+P3	288.5	175.8	26	74	0.2049	0.1658	26,822,375	14,837	1114.58
23	P1	P2+P3	292.9	175.8	25	75	0.2046	0.1658	26,759,172	14,802	1114.58
24	P1	P1+P2+P3	347.4	176.2	17	83	0.2527	0.1653	28,449,206	15,737	1114.58
25	P2	P1+P2	289.2	183.2	21	79	0.2051	0.1644	26,321,868	14,560	1114.58
26	P2	P1+P3	288.2	183.2	21	79	0.2051	0.1644	26,334,078	14,567	1114.58
27	P2	P2+P3	292.6	183.2	21	79	0.2048	0.1644	26,274,615	14,534	1114.58
28	P2	P1+P2+P3	347.0	183.2	14	86	0.2530	0.1644	27,575,711	15,253	1114.58
29	P3	P1+P2	289.5	177.1	25	75	0.2049	0.1655	26,722,927	14,782	1114.58
30	P3	P1+P3	288.5	177.1	25	75	0.2050	0.1655	26,738,244	14,790	1114.58
31	P3	P2+P3	292.8	177.1	25	75	0.2047	0.1655	26,673,736	14,754	1114.58
32	P3	P1+P2+P3	347.3	177.4	17	83	0.2528	0.1651	28,297,194	15,653	1114.58

When the costs associated with the combinations were examined in the output on Table 5, it was seen that the combination “11” was having the least cost. When the combination “21” which was used in real application by the operator, was compared with the combination “11”, it was seen that approximately 3.66 % saving could be achieved. In overall 4.35 % cost saving was achieved for this particular case.

CONCLUSIONS

Different examples were worked out using SCADA data concerning both on past data and real time applications using geographic information systems (GIS). It was found out that efficient pump combinations reduces energy costs considerably. The magnitude of the savings varies 5%-10% depending on the case studied. The reduction increases if the pressure on the suction side differes from the design pressure. A procedure was offered also for using the proposed methodology to be handled by system operators.

REFERENCES

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