Solving Optimal Pump Control Problem Using Max-Min Ant System

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1. PUMP SCHEDULING PROBLEM

Given a water distribution network, where customer demands, initial tank levels and electricity tariffs are known, the goal is to find the optimal pump schedule over a time period, typically 24 hours, such that the cost of energy consumed by pumps (C_E) and maintenance costs are minimised and constraints are satisfied. The electricity tariff is typically divided into an expensive peak and cheaper off-peak periods, while the actual amount of energy consumed by a pump depends on several dynamic factors. For a given schedule, its energy cost can be calculated using a hydraulic simulator (EPANET [1] in our case). On the other hand, maintenance costs are typically assumed to increase with the number of pump switches (N_S), since frequent switching, that is, turning on a pump which was previously off, causes wear and tear. Typically, this objective is incorporated as an additional constraint. In our approach, this constraint is implicitly enforced by the representation. As for system constraints, such as mass and energy balance equations, and tank minimum and maximum levels, they are implicitly enforced by EPANET. Operational constraints must be explicitly handled: (i) zero total volume deficit, defined as the total sum for all tanks of positive difference in percentage between the initial and final volume of water in a tank; (ii) zero pressure deficit, since consumers must be supplied water at adequate pressures; and (iii) no warnings reported by the simulator.

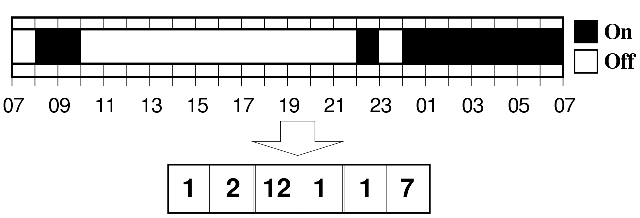

Figure 1: Time-based triggers representation.

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2. APPLICATION AND CONCLUSIONS

We apply Max-Min Ant System (MMAS) [2] to solve the pump scheduling problem. Instead of the typical binary representation, we use a representation based on *time-controlled triggers*, where for each pump there is a vector of integers and each pair of integers defines the number of hours that a pump is off and on. Thus, the total number of pairs corresponds to the maximum number of switches per pump (S). And example for $S = 3$ switches is shown in Fig. 1. A different pheromone matrix is used for each pump, and a pheromone value τ_{ij} is associated to the assignment of a number of hours j to a particular time interval $i = 1, \ldots, S$. The last interval is assigned a number of hours such that the total duration of the schedule is 24. By allowing j to take a value between 0 and 24, the constraint on switches per pump $N_S = S$ is relaxed as $N_S \leq S$.

The approach is compared to results obtained by a Hybrid Genetic Algorithm (HybridGA) [3] on the same instance (3 pumps and 2 tanks) and for the same number of evaluations (6000) per run. Table 1 shows results for values of parameters of MMAS [2] that obtained the lowest median electrical cost (averaged over 25 runs): $a = 50$, $\rho = 0.9$ and $p_{\text{best}} = 0.85$ for constraint $N_S < 9$; and $a = 50$, $\rho = 0.95$ and $p_{\text{best}} = 0.5$ for $N_S \leq 9$. The results obtained by MMAS are similar to those obtained by Hybrid GA. The number of pump switches is notably reduced by relaxing the constraint, although at the expense of slightly higher electrical cost. This could be attributed to the larger solution space explored when less pump switches are allowed.

Table 1: Comparison of MMAS and HybridGA

	MMAS		MMAS		Hybrid GA	
	C_E	$N_S = 9$	C_E	$N_S \leq 9$	C_E	N_S
median	339.4	9	348.0	4	347.1	4
sd.	10.7	0	6.5	1	4.3	1
best	330.7	9	341.6	3	344.4	3
worst	361.7	9	361.7	7	354.8	5

3. REFERENCES

[1] L. A. Rossman. The EPANET Programmer's Toolkit for analysis of water distribution systems. In *Proc. of the Annual Water Resources Planning and Management Conference*, Reston, USA, 1999. ASCE.

[2] T. Stützle and H. H. Hoos. $\mathcal{MAX}$–$\mathcal{MIN}$ Ant System. *Future Generation Computer Systems*, 16(8):889–914, 2000.

[3] J. E. van Zyl, D. A. Savic, and G. A. Walters. Operational optimization of water distribution systems using a hybrid genetic algorithm. *Journal of Water Resources Planning and Management, ASCE*, 130(2):160–170, Mar. 2004.