

Optimization of Pump Station Operation Saves Energy and Reduces Carbon Footprint

Alex Ekster Ph.D.,P.E.,D.E.E.

Ekster and Associates Inc.

1904 Lockwood Avenue, Fremont, Ca 94539, alex.ekster@srtcontrol.com

ABSTRACT

A new methodology has been developed for pump stations optimization. The methodology uses simultaneously generalized reduced gradient and genetic algorithms. The methodology allows optimization of any combination of constant speed and variable speed pumps. Implementation of this methodology at one pump station yielded reduction of energy usage as much 25% that was equal to more than \$50,000 a year.

KEY WORDS: pump station, energy savings, optimization, pump station optimization,

INTRODUCTION

In 2001 California spent 18,600 Gwh per year only on agricultural and water pumping (http://www.energy.ca.gov/electricity/consumption_by_sector.html). In addition, pumping is widely used in power industry, HVAC, etc. Considering that each kw*hr of energy saving causes 0.537kg of carbon emission reduction, decrease of energy usage helps not only to improve the bottom line but also leads to reduction of carbon footprint.

According to extensive European studies (ETSU 2001), 76% of all pumps are centrifugal pumps. Most of large and medium size centrifugal pumps are operated in parallel. Minimum energy consumption of a pump station can be achieved by setting in real time an optimal combination of sizes of pumps operating in parallel and speeds of variable frequency drives (VFD). Selection of such combination is a fairly trivial task when the pumps operated in parallel are exactly identical. This task becomes, however, very complex when pumps operated in parallel are not identical or when VFDs are used. This paper describes methodology that allowed overcoming these challenges.

METHODS AND MATERIALS

Optimal scheduling of pumping stations was extensively studied by researchers for at least last 25 years. Ormsbee and Lansey (1994) provided a good summary of methods used for optimization of water supply systems operation and design. Creasy (1988) concluded that proper pump scheduling could save United Kingdom at least ten million pounds a year. Until recently, however, there were significant limitations of mathematical tools available for optimization due to discrete and non-linear nature of an optimization task. Ormsbee (1991) suggested that on-off operation of pumps poses a difficulty for optimization techniques that require continuous functions.

Non-linear programming

Recently, when tools for non-linear programming became readily available, several attempts to address pump optimization problem have been undertaken (Ormsbee et al., 1989, Zessler and Shamir, 1989, Mays and Tung, 1989, Sakarya et al., 2000, and others).

For example, the nonlinear programming approach proposed by Brion and Mays (1991) evaluates gradients using finite differences, or a mathematical approach to provide derivatives required by Generalized Reduced Gradient (GRG2), which solves nonlinear optimizations problems by using the generalized reduced gradient method (Lasdon et al., 1978). The latter method has been used for scheduling pump operations to minimize energy and improve water quality by Sakarya (1998) and Sakarya and Mays (2000). Dynamic programming has been used for the optimal scheduling of pumps in a water distribution system by Coulbeck and Orr (1982) and Coulbeck, Brdys and Orr (1987).

This approach, however, has certain shortcomings. First is the “curse of dimensionality” (Mays and Tung, 1992), caused by an increase of problem size when number of discretizations and state variables increase. It sometimes restricts the application of this method to small systems. In addition, a possibility exists that this approach will select local minimum rather than global minimum. Finally, software that utilizes this approach may take a very long time to converge.

Genetic algorithm

Over the course of the last three decades computer algorithms that mimic certain principles of nature have proven their usefulness. Researchers have found especially worth copying those principles for addressing such optimization challenges as non-linearity and selection of global minimum rather than local one, i.e. challenges that conventional optimization algorithms have problems addressing.

Over many generations, natural populations evolve according to the principles first stated clearly by Charles Darwin. The main principles are those of preferential survival and reproduction of the fittest members of the population. Additional principles that characterize natural systems are the maintenance of population with diverse members, the inheritance of genetic information from parents, and the occasional mutation of genes. *Evolutionary Programs* (EPs) are general artificial-evolution search methods based on natural selection and the aforementioned mechanisms of population genetics. This form of search evolves throughout generations, improving the features of potential solutions by means of biologically-inspired operations. Although they represent a crude simplification of natural evolution, EPs provide efficient and extremely robust search strategies.

Genetic algorithms (GA) are probably the best-known type of EP. Although called an algorithm, a *genetic algorithm* is actually an adaptive heuristic method. It has achieved fame among analysts and engineers for its ability to identify good solutions to previously intractable problems. During recent years, GAs have been applied to hydraulic network optimization (calibration, design, and pump scheduling) with increasing success (Macle et al., 1995, Savic et al, 1997, Rodin, 1998, W. de Schaetzen, 1998, Sotelo et al., 2002, Boulous, 2001, Moradi-Jalal et al., 2004, and others).

A genetic algorithm (GA) can provide good answers for large, complex, discontinuous, multi-modal spaces. It can also be used for domain exploration, mapping out previously unexplored portions of a large design space. In exchange for its flexibility and robust processes, GA does not provide the optimum solution but rather a solution that is close to the optimum.

New development

Works described above had the following limitations:

1. Optimization was used only for fixed speed motors.
2. A formal mathematical model of the distribution system was required.
3. Instead of actual performance curves the manufacturers' curves were used.

The prerequisite for the development of the optimization algorithm is determining the relationships between pressure, flow, pump speed and power consumption. To determine pump operation at different speeds an affinity law was applied. Efficiency and pumps heads were modeled as polynomials. Instead of a formal mathematical model of the distribution system, a regression model was used.

The goal of optimization was minimum energy usage. In addition, the algorithm allows limiting time between two starts of the same pump to avoid motor overheating.

An optimization algorithm utilizes both GRG and genetic algorithms. The selection of optimum pump schedule and VFD speeds is confirmed when both methods provide similar results.

To determine actual performance of a pump, power consumed at each speed needs to be monitored by power meters. Flow is monitored by any type of a flow meter, pressure is monitored by pressure gages, and a wet well level is monitored by any type of a level meter.

Monitoring performance of the operating pumps has it challenges. Usually the difficulty lies in the fact than individual pumps are not equipped with flow meters, and only the entire pump station has a flow meter. If this is the case, a special pump testing protocol needs to be developed to determine individual performance of each pump. Based on the results of the monitoring, the multiple equations need to be developed and then solved simultaneously.

Pump station description

The discussed above methodology was used for optimization of the pump station equipped with seven pumps. Pump station description is given in Table 1. Average dry weather flow is 110 MGD. Ratio between maximum and minimum daily dry weather flow is 3.2. Maximum wet weather flow is 280 MGD. Average hourly power usage is 62 KW*hr/MG. Standard operating schedule during dry weather includes operating one constant speed pump and one variable speed pump. Standard operating procedure for wet

weather is operating three pumps instead of two pumps. The criterion for pump selection in operation was an equalizing number of hours in operation for each pump.

Table 1. Design data for the optimized pump station

PUMP#	FLOW, MGD	HEAD, FT	TYPE OF DRIVE	MOTOR POWER, HP
1	34	23	CONSTANT SPEED	200
2	34	23	CONSTANT SPEED	200
3	34	23	CONSTANT SPEED	200
4	34	23	CONSTANT SPEED	200
5	110	16.5	VARIABLE SPEED	400
6	110	16.5	VARIABLE SPEED	400
7	120	16	VARIABLE SPEED	400

RESULTS

Comparison of field data with manufacturers' data showed the following:

- Head of the best efficiency point of variable speed pumps is close to field measurements, while head of the best efficiency point of the constant speed pump is much higher than required.
- Pump #6 performs close to the original manufacturer's data
- Mechanical efficiency of pump #5 is similar to the original manufacturer's data, while electrical efficiency is lower, probably, due to larger service factor of the motor.
- Pump # 7 performs less efficiently than could be expected based on the manufacturer's data. While currently there is no opportunity to inspect pump #7, such inspection is scheduled for the future.

Based on the software output the new service schedule has been developed (see Table 2). Operation of pumps according to this schedule allowed reduction of energy usage from 62KW*hr/MG to 46KW*hr/MG. This reduction yielded savings of more than \$50,000 a year.

Table 2. Optimized pump service schedule

FLOW, MGD	PUMP	TYPE OF DRIVE	FLOW DISTRIBUTION
UP TO 90	#6	VARIABLE SPEED	100%
90-185	#5, 6	VARIABLE SPEED	50%/50%
185-250	#5, 6, 7	VARIABLE SPEED	37.5%/37.5%/25%
250-290	#5, 6, 7	VARIABLE SPEED	90MGD/90MGD/VAR

DISCUSSIONS

Installation of power meters allows determining compare real power consumption with the power consumption of the pump when it was new. Only one out of three pumps equipped with VFD consumed as little power as it was expected according to the original manufacturing data. Based on this comparison it was possible developing a schedule for pump retrofit.

The fact that actual pump performance was differ from the expected performance shows that optimization of pumps operation should be based on field data whenever possible.

Developed methodology of optimization that is based on using both evolutionary and GRD algorithms allowed independent confirmation that selected mode of operation at each flow is the best from energy perspective. The fact that the selected minimum was global rather than local is a big advantage of the selected method. Another advantage is the fact that no formal mathematical model of the distribution network was needed for optimization. As a result, significant efforts were saved, that traditionally were needed for optimization of pump stations. The fact that used methodology allowed selection not only the pumps to be used at each flow but also the speed of each pump yielded significant energy savings.

Optimized operation schedule recommended using only pumps equipped with VFD. However, it does not mean that, in general, pumps with VFD consume less energy than constant speed pump at any flow. The particular pump station was just equipped with the constant speed pumps that were not fitted very well for the distribution system. If different constant speed pumps were used, it is very possible, that at certain flow range, operation of some of these pumps in conjunction with pumps equipped with VFD would be more economical than combinations presented in Table 2.

CONCLUSIONS

- Comparison of field data with manufacturer data allowed determining pump condition
- Optimization based on field data provides better results
- Developed new optimization method was very robust and allowed developing an optimization schedule that selects pumps to be in operation and their speeds.
- Developed optimized schedule allowed saving of 16KW*HR/MG which equal to almost 25% energy savings.

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