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OPTIMIZE ENERGY MANAGEMENT TECHNIQUES TO DECREASE OPERATIONAL COSTS IN WATER TREATMENT PLANTS AT NO INVESTMENT BASED ON IMPROVED PUMPS OPERATION SCHEDULES.

Nader SH. Abdelhakeem[1], Mohamed I.S. Abodief[2*], Mohamed I. Elsayed[2]

[1]Electrical Engineering Department, Faculty of Engineering (Shoubra), Benha University,. Shoubra, Cairo, Egypt,

[2]Electric and Machine Department, Faculty of Engineering, Al-Azhar University, Nasr City, 11884, Cairo, Egypt.

***Correspondence:** mohame.abodief@hcww.com.eg

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ABSTRACT

The pump units are the main water treatment plant (WTP) equipment, and their operating and maintenance costs are considerable in their life cycle cost. optimize pump operation is essential and significant for improving the efficiency of asset management and developing an operation strategy. The pump's energy consumption costs share a range of 30–50% of the overall operating cost, with a potential 10% savings by optimizing operation. Energy management is one of the most widely used optimization objectives in pump systems, as it has direct improvements to the whole WTP life cycle, such as environmental impact and operational costs. Our methodology is a combination of using a linear model for forecasting the production of the water plant and optimizing operation costs, where it forecasts the water demand at any given time in parallel with optimization algorithm to generate the proper pump operation schedules for the demand. We have set the energy management parameters related to the WTP operational cost. The Matlab optimizer has defined several different pump schedules based on the input data sets related to the variable water demands throughout the day and in each season, and achieved the main optimization objective of cost reduction. The energy cost of each schedule has been presented according to the main energy management factors, such as cost, maximum demand, and efficiency. This research presents the effects of decreasing pump set operational costs in a conventional WTP in Egypt through improved energy management based on water demand forecasts.

KEYWORDS: Water supply systems, Operational control optimization, Energy and cost efficiency, Improving Energy management, Artificial intelligence in WTP.

تحسين تقنيات إدارة الطاقة لتقليل تكاليف التشغيل في محطات معالجة المياه بدون استثمارات بناءً على جداول تشغيل المضخات المحسنة.

نادر شوقى عبد الحكيم[1] ، محمد اسماعيل ابوضيف[2]*، محمد إبراهيم السيد[2]

[1] قسم الكهرباء قوى والات كهربيه، كلية الهندسة بشبرا ، جامعة بنها، شبرا، 11689، القاهرة، مصر.
[2] قسم الكهرباء قوى والات كهربيه، كلية الهندسة، جامعة الأزهر، مدينة نصر، 11884، القاهرة، مصر.
***البريد الاليكتروني للباحث الرئيسي :** mohame.abodief@hcww.com.eg

الملخص

وحدات الضخ هي المعدات الرئيسية لمحطة معالجة المياه تمثل تكلفة إمتلاك الأصول مثل وحدات الضخ أو أى مرافق أخرى جزءاً من التكلفة التشغيلية الإجمالية لمحطات معالجة مياة الشرب .يعتبر حساب التكلفة التشغيلية خلال دورة حياه وحدات الضخ مهما لاسباب عديده منها تحسين كفاءة إدارة الأصول ووضع استراتيجية لتشغيلها مناسبه. المضخات هى المعدات الرئيسية في محطات تنقية مياه الشرب وتتراوح تكاليف الطاقة الكهربائية لتشغيل المضخات من 30 إلى 50 بالمائة من إجمالي تكلفة التشغيل مع فرص لتوفير 10٪ من هذا الاستهلاك عن طريق تحسين التشغيل. تعد إدارة الطاقة الجيده واحدة من أهم أهداف التحسين المستخدمة على نطاق واسع في أنظمة المضخات لأن لها مردود على جوانب أخرى من دورة حياة محطات تنقية مياه الشرب مثل التأثير البيئي والتكاليف التشغيلية. المنهجيه المتبعه هي مزيج من نموذج خطي للتنبؤ بإنتاج محطة المياه لتحسين تكلفة تشغيل المضخات, حيث يتم التنبؤ بكميات المياه المطلوب انتاجها في أي وقت خلال اليوم وبناءا على ذلك تقوم خوارزمية التحسين المدمجة ببرنامج ماتلاب لإدارة الطاقة. كما تم إنشاء نموذج خطي لإنتاج محطة المياه لدراسة سلوك تقنية التحسين المقترحة لاستهلاك الطاقة من خلال إعادة جدولة تشغيل المضخات لتتكيف و تتناسب مع الانتاج المياه المطلوب مع قياس معايير إدارة الطاقة المتعلقة بالتكلفة التشغيليه في محطة تنقية المياه. حيث تنشأ خوارزمية التحسين عدة جداول زمنية مختلفة لتشغيل المضخات بناءً على مجموعات البيانات المدخلة المتعلقة بمتطلبات المياه المتغيرة على مدار اليوم وفي كل موسم، وبالتالي يتم اختيار جداول تشغيل المضخات الأكثر ملائمة لتحقيق هدف التحسين الرئيسي المتمثل في خفض التكاليف. تم عرض تكلفة استهلاك الطاقة لكل جدول تشغيل وفقًا لعوامل إدارة الطاقة الرئيسية، مثل التعريفة والحد الأقصى للطلب وكفاءة النظام. يعرض هذا البحث آثار خفض التكلفة التشغيلية لوحدات المضخات في في محطات معالجة المياه التقليدية في مصر من خلال تحسين إدارة الطاقة بها بناءً على توقعات الطلب على المياه

الكلمات المفتاحية : محطات مياه الشرب، تحسين التحكم التشغيلي، كفاءة الطاقة والتكلفة، تحسين إدارة الطاقة، الذكاء الاصطناعى في محطات مياه الشرب.

1. INTRODUCTION

Urban water sources are becoming more dependent on electricity for both treatment and transportation as a result of growing water needs, and the need for electricity availability will become significant in the future due to augmenting and limited sources of water, which will lead to water shortages and change the water sources to be more dependent on desalination with more world efforts to confront its environmental effects. So, electricity costs and availability could have an impact on sustainability in urban areas, and could lead to water supply problems up to a water crisis and even pollution (Singh, 2012), and there is a need to increase the role of energy efficiently and more on renewable sources [1, 2, 3].

The water system is confronted with issues like growing energy costs, ageing infrastructure, and increased water demand, and on the other side, there are possibilities for increasing investment in renewable energy to lessen swings in energy prices, making the effective operational administration of the water supply system a challenging issue [4]. On the other hand, increasing concerns about the environment and climate change have led research towards the classification of energy conservation and energy efficiency as global development strategies [5].

The importance of more research on the relationships between energy, water, and sanitation systems is growing in order to meet future environmental challenges. This challenge has a great impact on developing countries due to their limited ability to meet the current energy demand in a green way, as well as having an impact on future predictions of energy demand. On the cost side, drainage accounts for about 75% of total operating costs of supply, treatment, and distribution to meet demand (US Department of Energy, 2006). The future water supply scenario is a mix of comparative economics and life cycle analysis.

Therefore, energy and its cost effect, as well as the environmental aspect of drinking water and wastewater systems, become important in making decisions related to the development programs of those systems [6]. This cost factor is a key idea in asset management and cost reduction, and life cycle costing is effective for forecasting and evaluating the overall cost and performance of assets, according to various researchers [7, 8]. [9, 10] Analysis of an asset's performance, condition, and life span is one of the key factors in enhancing asset maintenance, in addition to improving maintenance [11] or researching the environmental effects of greenhouse gas emissions [8]. According to the famous Delphi approach, the life cycle of the pump unit is usually classified and grouped into four major focus stages [12] and may extend to six [13]. It begins with the initial stage, followed by the operation stage, the maintenance stage, and finally the disposal and replacement stage. According to the findings of a study on the life cycle costs of 50 water stations [14], the cost of operation and maintenance, particularly, contributes to 72.52% of all costs, and it acts as the key cost driver, taking into consideration many barriers against improvement due to a lack of reliable information [15]. The electrical cost of operating pumps in water distribution systems ranges from 30% to 50% in general, and they are most commonly used at centrifugal pump stations. Pumps use around 20% of the world's total energy [16]. According to various pieces of literature, optimizing pump operation has a significant impact on the water sector, which can result in savings of up to 20% in yearly energy expenditures [17]. So, many researchers have applied optimization to the water network, including water pumps in the WTPs, with different methodologies; some use hybrid renewable energy systems for environmental prospects [4], while others have simultaneously energy costs and water quality [18], while on the other side, the authors may use different optimization algorithms to achieve many objectives [15].

In our research, we have selected optimization research in a country that applied the same types of energy tariffs as Egypt [19]. To check the feasibility of the generated schedules as the EPANet software simulator, he proposed a hyper combination of the EPANet simulator with the optimization algorithms to reduce the cost by optimally controlling the (on/off) control of water pumps. The paper's findings indicate that the optimization schedules will decrease the energy consumption cost of the pump station by a percentage cost saving of 36.3%, which indicates that the most effective water pump schedules considerably reduce the cost of energy use. Their system constraints include water node pressure in the water network and water tank levels. The artificial electric field algorithm (AEFA) was used to optimize the results, and comparing it with other optimization algorithms such as the genetic and particle swarm, the results indicate that the AEFA increased optimization by 1% against other algorithms. The complex nature of water networks in general and the nonlinearity of the hydraulic system's behavior under varying schedules make the process difficult. Due to the complexity of water networks and the nonlinear behavior of water flow, none of these approaches are perfect. Furthermore, especially in developing countries like Egypt, where the limited availability of pressure meters (manometers) to cover their networks is due to their considerable cost, decision-makers may need to encourage investing in using suitable optimization techniques in the existing WTPs.

In a similar approach to this research, the novelty of our optimization research is the different approach of modeling, as we depend on replacing the driven optimization of the other research that depends on the water network pressures at endpoints of networks with forecasting the water demand and output pressure at the beginning of the network (the end of the WTP) for each day, which refers to the ordinary operation and reflects the suitable pressure and decreases the required cost of optimization. Then we used the Matlab integrated optimization algorithm to generate suitable pump schedules and optimize the energy management factors. Also, the system curve almost always tends to be flatter when many pumps are in parallel operation to reduce system friction losses. Their increased flow will lead to an increase in fluid friction losses, which will lower the system's overall efficiency and use more energy, so additional aspects will be taken into consideration to enhance the parallel operation system of variable capacity pumps, lowering system friction based on arranging the starting of the operation pumps by decreasing the internal friction between the operation pumps, as in [17].

In our research paper, we have considered the change in efficiency value between parallel-operated pumps by selecting the lowest-efficiency units to start operation first before others. Our research site was located in the north of Egypt, in Mansoura city. It’s one of the biggest WTPs, with a rated capacity of 800 L/s and an energy consumption cost of about 19 million EGP annually (for a special tariff of 1.25 egp/kwh). This cost has increased significantly by 200% in the last decade, and it is predicted to continue increasing at the same percentage.

Matlab software was used to model the water networks and assist in determining the best pump operation schedules. We have selected multi-objective (GA), as it is a popular optimization algorithm that offers a flexible and powerful approach to solving complex optimization problems in efficient and effective ways. It can generate robust and flexible pump schedules and handle system constraints; furthermore, it is used as the basis of development by integrating with other optimization methods to create hybrid approaches.

The goal of improving the energy management system is to increase its ability to solve a variety of new and updated problems in addition to the main design objectives of the system. Energy consumption in water treatment plants was analysed in several research studies based on different objectives, some studying its direct impact on costs. In [20], the impact of energy costs as a percentage of operating costs in WTP has reached almost 20%. In [21], the impact is measured based on the specific energy consumption expressed in kilowatt-hours consumed per cubic meter of treated water. The energy consumption is analysed in view of energy-saving solutions and the impact of renewable energy resources on the life cycle assessment.

Many researchers, as was done in [22, 23], analyse electrical consumption in view of its direct impact on the quality of the production process and the required production quantities, as well as the insights of the future trend towards increasing greener electricity in WTPs by using renewable sources. The operating and maintenance (O&M) expenses in WTPs have the highest energy contribution in the first high cost, reaching 30%, and the pump systems are the largest energy consumers in the WTPs. Energy efficiency was improved in operating the pumps as a primary goal to lower operational costs, with many other aspects relevant to the pumping system, such as improving reliability or resolving scheduling problems with the pumps [24].

The old objective of optimization was to reduce maintenance costs, while the new research tries to discover a new strategy to decrease them by decreasing the pump's working time, as in [16]. Operating cost is an important element in the life cycle cost (LCC) of water plants as well as the equipment, so it is still the focus of attention for many researchers, either as a general main goal as in [25] applied to the whole site or as a primary goal to promote other side goals such as the environmental goal as in [26], which combines many improvement goals in reducing environmental impacts and increasing system reliability while reducing LCC. Whereas in [27], I incorporate it with the new objective of minimizing harm to human health while also maintaining the reliability of the supply and demand systems and reducing LCC.

In [28], he developed the main objectives of sustainable improvement to include the vision of improving the operational cost of environmental, economic, and social benefits, with a comparison of the results using different improvement techniques: GA, PSO, and BFPSO. The author used an integrated multi-criteria framework in [29] to evaluate the improvement of the distributed energy system in a multi-objective, non-linear system.

1.3. Problem formulation.

Reducing the cost of energy consumption means, in the minds of many, pumping investments and using new units with high efficiency or alternative sources of electricity that have a lower cost, but in the current situation of many stations in Egypt, the problem is reducing the cost of energy consumption with as little investment as possible and improving the specific energy consumption (SEC) while maintaining the current system efficiency, which may conflict with the energy reduction objective for increasing the output, no matter that increasing the operation system efficiency is the main objective for the water plant strategy.

To improve the overall system operation by adapting to the energy objective, there are two approaches: the first is increasing the flow of the existing pump units by decreasing the internal friction due to the parallel pump operation, which improves overall system efficiency. This will be based on rescheduling the start of the pump units to start with the pump that has the lowest efficiency and gradually work up to the pump that has the highest efficiency. This will decrease the effect of recirculating pressure between parallel-operation pumps and increase system flow. Another approach is to increase the time of operation of the efficient pump units over the share of less efficient units to increase the overall efficiency of the system and increase the output. Therefore, the most suitable scope of the work will depend on optimizing the operation schedule of the main pumps at the site using a genetic algorithm.

1.4. The main contributions of the paper.

The main contributions of this paper are as follows:

I. Proposing an optimize energy management technique to decrease energy costs in water treatment plants with no or low cost

II. Analysis of the energy profile in the selected pump system to define the best operation scenarios with its energy performance indicators by using many optimization algorithms to reach the best water pump static scheduling that satisfy all objectives.

III. The objective function of this paper is a multi-term objective function that formulates the objective function for many targets:

A. Reducing electrical consumption (f1). B. The maximum load over the entire day (f2).
C. Improve the overall system operation (f3).

Through this paper, we will review the improvement of operational costs as the main objective by focusing on improving energy management and increasing the overall efficiency of the system. Accordingly, this paper is organized as follows: In Introduction Section 1.2, related work to optimize energy management and operational costs of pump systems and previous contributions are presented. in 1.3 and 1.4 represent the problem formulation and the main contributions of this paper. Section 2 represents the formulation and calculation methods of the objective function. Section 3, presented Analyses the energy consumption behavior in the pump station and identifies the best operation scenarios and the proposed technique to reschedule the pumps. Section 4 introduces the results of the implementation of the energy management Optimize algorithms. Section 5, finally, is where the conclusions are presented.

2. CALCULATION METHODS.

Formulate the objective function.

The general equation that describes the objective can be formalized according to Equation.1

$$objective-function=\sum_{j=1}^{j=24}\min\left(f1+f2\right)+\max\left(f3\right) \qquad \text{Eq. 1}$$

Where f1 is the electric energy consumption consumed by the pump station, f2 is the maximum power demand, and f3 is the overall pump system efficiency as follows:

The energy consumption (F1).

According to the standard (ISO 50001) approach for developing energy management systems , identify the significant energy use in the water treatment plant. The pumping system is ranking first as it gained the most ranking points at the selection criteria based on its effect on the energy management system.

The research pumping system for potable water consists of six variable- capacity pumps. An energy check has been executed for the research pumping system. **Table 1** shows the measurement data for each pump unit for one-day measurement divided by 24.

Equations 2 describe the energy consumed by the pump station when running pump i during the time j, where j represents one hour consumed, P is the required electric power of pump i at the time instant j, and X is the is the operation state (0/1).

$$energyconsumed = f1 = \sum_{i=1}^{6} \sum_{j=1}^{j=24} X_{ij} P_{ij}$$ Eq. 2

P refers to motor consumption measured (Kwh) were obtained in **Table 1**, and X values are equal to 0 when the pump is stopped, and vice versa, x = 1 when the pump state is on (operating). Finally, the pump ID is i = 1; 2;... 6.

Table 1. The energy measurement data of the research pumping system.

		Source of data	Pump1	P.2	P.3	P.4	P.5	P.6
pumps data	**Rated flow L/s**	Name plate	500	200	400	400	200	200
	measured flow rate L/s	Flow meter	442	183	361	362	147	177
	Calculated efficiency. %	calculation	71	73	72	72	59	71
	Deliver head.	Pressure meter	Operating range 40:45 Meter					
motor data	**Motor rated power kw**	Name plate	500	224	440	355	224	224
	Energy consumption - kwh	energy meter	419	189	300	297	168	187
	load factor %	Calculation (CAL.)	84	84	68	84	48	83
	efficiency % based on LF		93	92	90	91	82	92
unit efficiency %		calculation		67	65	66	48	65

In **Table 1**, the motors manufacture dates are between 2004 and 2009, and according to the motor efficiency vs. motor load factor charts that were discussed by the author in Energy, Economic, and Environmental Analysis for Chillers in Officee Buildings 2010), the nominal motor efficiency is obtained when the motor load factor is around 80% and above, and it decreases according to the low load factor. So there's no proper change in their efficiency except motor no. 5, we assume.

The maximum power demand (F2).

The maximum power demands f2 over the specific period j = 1:24 across the day hours are calculated in Equation 3.

$$f2 = \max . \sum_{i=1}^{6} \sum_{j=1}^{j=24} X_{ij} P_{ij}$$ Eq. 3

The overall pump system efficiency (F3).

The overall pump system efficiency f3 characterizes the ratio of the pump's hydraulic energy output (PH) to energy consumed at input (E) for the operating point in Equation 4.

$$overallefficiency = f3_j = PH_j / E_j$$ Eq. 4

(PH) for the running unit i over the time duration j, is based on the pump discharge (q) and head of the pump (h), as next in Equation 5.

$$PHij = q_i^j * h_i^j * \rho$$ Eq. 5

Where ρ is a water density conversion coefficient assume (=1) for the drinking water. The pump discharge (q) will be obtained from Table 1 in L/S, and the head (meter) of the pump (h) will be obtained from the registered pump system in January and July, as shown in **Figs. 1** and **. 2.**

3. ANALYSIS SYSTEM PROFILE IN THE PUMPS STATION.

An analysis system profile generally offers an extensive overview of the capabilities, constraints, and performance of a system. This makes it possible to understand and optimize the system better, which enhances its cost-effectiveness, reliability, and efficiency. The pump stations consume the major share of energy at the WTP, and they act as the main and most significant energy use in the WTP according to the ISO50001 approach. An analysis of the pump system based on both electrical and hydraulic energy will be presented next.The behaviors of water use changes seasonally as it increases as the temperature rises and decreases as the temperature decreases. So, in Egypt, we will represent the usage behaviors at high temperatures for July month production, and in another way, we will represent the usage behaviors at low temperatures in Egypt by January month production.

3.1. System's demand analysis (F1).

The WTP's output hydraulic energy mainly depends on water production and the corresponding network head. The following graphs, **Fig. 1** and **Fig. 2**, represent in each of them the average values for the daily water production curves and the corresponding network head registered over days' time in both the January and July months, respectively.

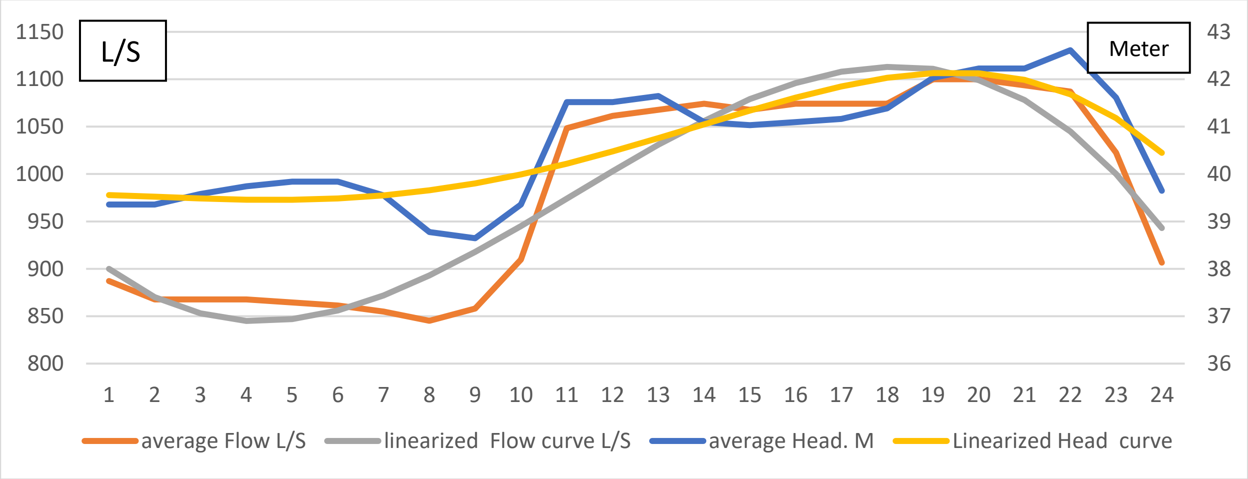


Fig. 1. January Production of the pump system along with the network head.

In **Fig. 1**, the graph approximately shows the minimum fixed flow over the day is 850 L/s; this value should work with the best efficiency pump units, while the maximum flow is about 1100 L/s, which is 29% above the minimum, and it needs more water production with about 3135 L/s above the fixed flow in the interval of 9:24 p.m.

In **Fig. 2**, the graph approximately shows that the minimum fixed flow over the day is 900 L/s, while the maximum flow is 1150 L/s (remarked as operation point 4), which is 27% above the minimum, and it needs more water production with about 3267 L/s above the fixed flow. The flow demand through the electricity peak period is 1100 L/s at 19:23 p.m.

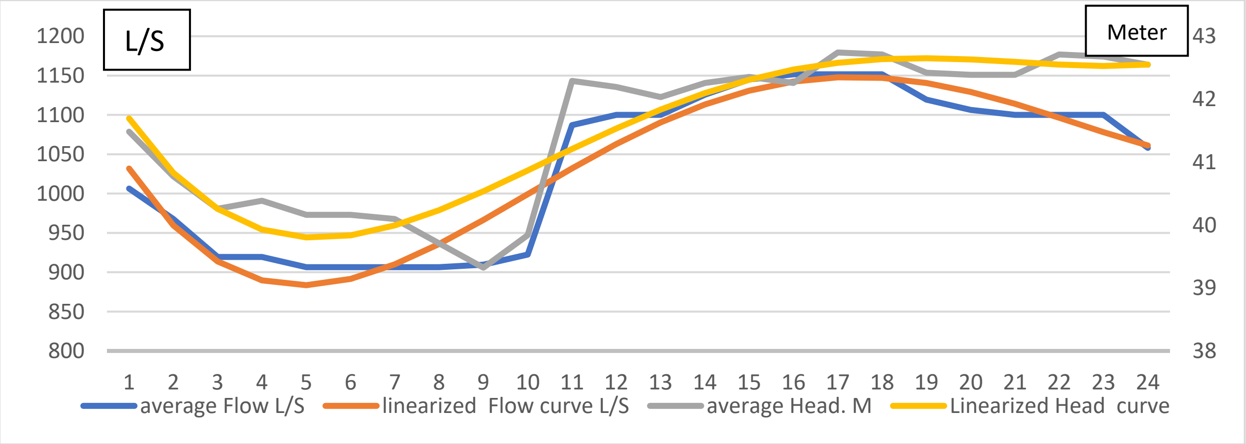


Fig. 2. July Production of the pump system along with the network head.

3.2. System's energy-cost parameters

There are many energy analysis parameters that can describe the behavior of energy in WTPs. The energy bill is the major cost driver for WTPs, so its cost has to be considered as the main key to the energy system. In Egypt, the energy tariff for the water and waste water works is subsidised, and it has a special tariff representing all tariff parameters that are applied to other works too. The normal energy tariffs depend on the voltage supply rate. It is divided into two main types (low voltage 380 v and medium voltage 3.3 11 22 kv); our site is supplied with medium voltage 3.3 kv, so the construction of participants for medium voltage participants consists of two types. One tariff that is related to the consumption amount over the day's hours (F1) is divided into two intervals with different costs; the lower cost is applied throughout the day except during peak periods that have a relatively higher consumption tariff.

The other tariff is related to the constant maximum load (F2) and depends on the maximum measured load in 15 continuous minutes, and it updates regularly as the load increases at any time over a specific interval (3 months). The full details about energy tariff types and costs in Egypt are updated and published periodically by the Egyptian electric utility and consumer protection regulatory agency.

The five W strategy (what, when, where, why, and who) can be used to identify more important parameters. The pump set is considered the main source of energy consumption through the operation process at WTPs, and it converts the consumed electrical energy to hydraulic energy in their output flow. The losses of electric energy are proportional to the efficiency of producing hydraulic energy (F3). The other issue that can describe the system operation effect on energy consumption is the specific energy consumption (SEC), which is noted as (F4) and expressed in kwh/m3 for the pump system at time instant j, and it’s calculated by Equation 6 for the energy consumed from all running pumps (F1) and the output flow QN .

$$f4j = \sum_{j=1}^{6} \frac{x_{ij} * p_{ij}}{QN_j} \qquad \text{Eq. 6}$$

Where X and P from eq. (2) specify the pump at a specified time j, while (QN) is the flow described by M3 and obtained from multiplying (3600) by the average flow values from curves in graphs 1, 2. The SEC will use this to obtain the energy needed to meet the water demand.The system efficiency (F3) and the corresponding (F4) are set to be the main parameters of energy analysis, in addition to parameters (F1) and (F2).

3.3. The system's energy parameter analysis approach.

We will divide the daytimes at the pump station into 2:3 intervals based on grouping the similar water flow behavior into one group, taking into consideration that peak water demand almost always registers at the same specific electricity peak time. Next, the best register of energy behavior has been defined for each period with its main energy parameters.

3.4. Analysis energy profile in the pump station .

The energy consumption parameters registered for January are in **Table 2**. According to the energy analysis approach we follow, the result of the energy analysis behaviour for January has been set as the best target performance for our optimization.

➢ At group #1 flow: 3042: 3364 M3, the interval times J at 1:9.

- The lowest (F1) is 693.5 KW at time 8.
- The best (F3) is 25.7%, and the lowest SEC (F4) is 0.213 Kwh/m3 at time 9.

➢ At group #2 flow: 3365: 3685 M3, the interval times J are 10: 12, 23, and 24.

- The lowest (F1) is 741.6 KW, obtained at time 24.
- The best (F3) is 25.9%, and the lowest SEC (F4) is 0.218 Kwh/m3 at time 24.

➢ At group #3 flow: 3685: 4007 M3, the interval time J is 13:22.

- The lowest (F1) is 863.9 KW at 15 p.m.
- The best (F3) is 28.1%, and the lowest SEC (F4) is 0.217 Kwh/m3 at time 18.
- The maximum demand (F2) is 888.4 KW, and it was registered at times 19 and 20.

In the same previous steps, the energy consumption parameters were registered for July in **Table 3**, and the results of the analysis are shown next and have also been set as the best target performance for our optimization.

➢ At group #1 flow: 3263: 3851 M3, the interval times J at 1:11, 24.

- The lowest (F1) is 730.1 KW at time 7.
- The best (F3) is 28.1%, and the lowest SEC (F4) is 0.222 Kwh/m3 at time 24.

➢ At group #2 flow: 3852: 4146 M3, the interval times J at 12:23.

- The lowest (F1) is 880 KW at time 22, 23.
- The best (F3) is 28.7%, and the lowest SEC (F4) is 0.222 Kwh /m3 at time 19.
- The maximum demand (F2) is 921.8 KW, and it was registered at times 17 and 18.

Table 2. The energy consumption parameters registered for Jan.

j	**QN m^3/h**	**PH Kwh**	**F1 Kwh**	**F3 %η**	**F4 Kwh/m^3**
1	3240	175	726.8	24.1	0.224
2	3132	169	709.1	23.8	0.226
3	3071	165	709.1	23.3	0.231
4	3042	164	710.2	23.0	0.233
5	3049	164	707.2	23.2	0.232
6	3082	166	704.3	23.6	0.229
7	3139	170	699.4	24.2	0.223
8	3215	175	693.5	25.2	0.216
9	3305	181	703.4	25.7	0.213
10	3402	188	744.2	25.3	0.219
11	3506	196	851.8	23.0	0.243
12	3611	204	861.6	23.7	0.239
13	3712	213	866.5	24.6	0.233
14	3802	221	871.3	25.4	0.229
15	3884	229	863.9	26.5	0.222
16	3946	236	868.3	27.1	0.220
17	3989	241	868.3	27.7	0.218
18	4007	244	869.8	28.1	0.217
19	4000	245	(888.4) **=F2**	27.5	0.222
20	3965	242		27.2	0.225
21	3881	236	883.3	26.7	0.228
22	3762	225	878.3	25.7	0.233
23	3600	211	831.2	25.4	0.231
24	3395	192	741.6	25.9	0.218
Results	**SUM 84,726**	**SUM 4,852**	**SUM 19,140**	**CAL. 25.5%**	**CAL. 0.226**

Table 3. The energy consumption parameters registered for July

j	**QN m^3/h**	**PH Kwh**	**F1 Kwh**	**F3 %η**	**F4 Kwh/m^3**
1	3623	223	807.2	27.6	0.217
2	3484	199	778.6	25.5	0.225
3	3310	184	740.6	24.9	0.225
4	3310	176	740.6	23.8	0.231
5	3263	174	730.6	23.8	0.23
6	3263	176	731	24.1	0.228
7	3263	181	730.1	24.8	0.223
8	3263	188	733.6	25.7	0.218
9	3275	197	738	26.8	0.212
10	3321	207	746.2	27.8	0.207
11	3914	218	876.7	24.8	0.236
12	3960	228	886.2	25.7	0.232
13	3960	237	885.2	26.8	0.225
14	4053	245	903.9	27.1	0.226
15	4123	251	916.8	27.4%	0.225
16	4146	255	919.4	27.8	0.224
17	4146	258	(921.8) **=F2**	28.0	0.223
18	4146	258		28.0	0.223
19	4030	257	894.6	28.7	0.218
20	3983	254	885.2	28.7	0.218
21	3960	250	881.7	28.4	0.220
22	3960	246	880.2	27.9	0.223
23	3960	242	880.2	27.5	0.227
24	3809	238	847.2	28.1	0.222
Results	**SUM 89,524**	**SUM 5.342**	**SUM 19,977**	**CAL. 26.7%**	**CAL. 0.223**

3.5. The proposed optimizer techniques.

I. The optimize objective.

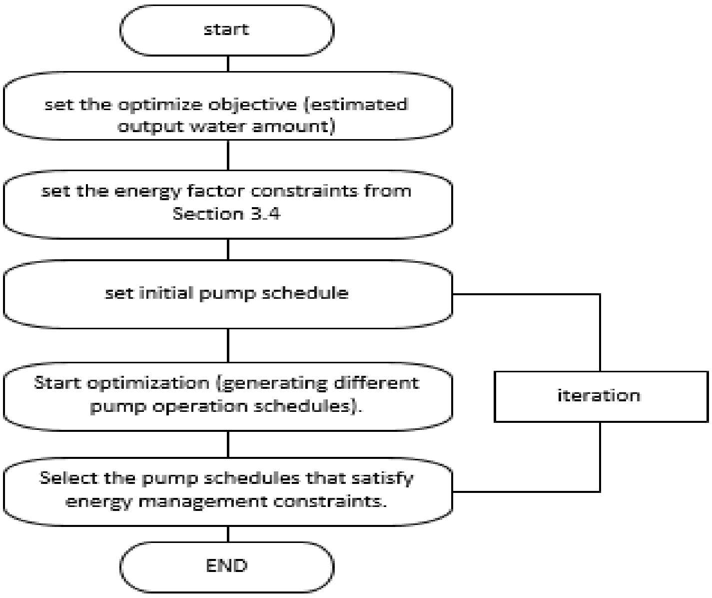
The genetic algorithm has been used to optimize objective Eq. 1 by generating different pump operation schedules that satisfy energy management constraints and produce the expected required water flow, which was determined for each time group from the QN columns in tables 2 and 3. The flow ranges have been set as optimize constraints.

II. The optimizer constraints.

The optimizer will calculate the effect of each operation schedule based on comparing the four energy parameters F (1:4). We have set them as optimizer constraints with different values according to the operation time.

III. The optimizer variables.

The pump's operation status (X1:6) is set as the optimizer variable, as there's not any speed control installed on the pumps, so the values of (X) have a set value of 1 or 0.



This flow chart represents simply one optimization cycle, and this optimization cycle was repeated for 1000 iterations. Every output is saved and compared with others to find the optimal solution.

4. RESULTS AND DISCUSSION.

New operation schedules for January and July days have been identified by the optimizer with their energy management parameters, as shown in **Table 4** and **Table 5**, respectively. The decrease in energy consumption due to the decrease in water production amount hasn't been included in the final saving results; it has been calculated by multiplying this amount of water flow reduction by the new specific energy consumption (217 and 221 watt/m3) for January and June, respectively.

The monthly operating expenses (OPEX) savings in the period from January to June will be ~ 23,137 EGP / month, To obtain the saving, compare the total results in **Table 2** and **Table 4** in the last rows as follows:

- The total January production will vary by -1.4%.
- Overall system efficiency η will improve by +3.4%.
- The electrical energy consumption will decrease by -4% (771 Kwh per day) and the specific energy consumption by 4.1%.
- The maximum demand will decrease by 6%.

The monthly operating expenses (OPEX) savings in the period from June to January will be ~ 6,423 EGP/month.To obtain the saving, compare the total results in **Table 3** and **Table 5** in the last rows as follows:

- The total July production will vary by -6.5%.

- The overall system efficiency η will improve by +0.3%
- The electrical energy consumption will decrease by -1.1% (214 kwh per day) and the specific energy consumption by -2%.
- The maximum demand will decrease by -9.4%.

Table 4. optimize operation schedule for January.

j	pumps schedule	Flow m^3/h	PH Kwh	F1 Kwh	F3 %η	F4 Kwh/m^3
1	P5P6P1	3305	179	693.4	25.8	0.210
2		3305	179	693.4	25.8	0.210
3		3240	179	693.4	25.8	0.214
4		3240	179	693.4	25.8	0.214
5		3321	179	693.4	25.8	0.209
6		3321	179	693.4	25.8	0.209
7		3321	179	693.4	25.8	0.209
8		3289	179	693.4	25.8	0.211
9		3272	179	693.4	25.8	0.212
10	P5P3P4	3600	199	705.2	28.2	0.196
11		3564	199	705.2	28.2	0.198
12		3510	199	705.2	28.2	0.201
13	P5P4P1	3802	218	834.7	26.2	0.220
14		3762	218	F2 =834.7	26.2	0.222
15		3703	218		26.1	0.225
16		3643	217	834.7	26.0	0.229
17		3604	217	834.7	26.0	0.232
18		3564	217	834.7	26.0	0.234
19		3544	216	834.7	25.9	0.236
20		3544	216	834.7	25.9	0.236
21		3564	217	834.7	26.0	0.234
22		3623	217	834.7	26.0	0.230
23	P5P4P3	3384	198	705.2	28.1	0.208
24		3528	199	705.2	25.8	0.210
Optimize results		SUM			Calculation	
		83550	4,777	18,113	26.4	0.217
The current operation output		84,726	4,852	19,140	26	0.226
difference		-1,174	-75	-1,026	0.9	-0.009

Table 5. optimize operation schedule for July.

j	pumps schedule	Flow m^3/h	PH Kwh	F1 Kwh	F3 %η	F4 Kwh/m^3
1	P5P3P4	3294	197	705.2	27.9	0.214
2		3456	199	705.2	28.2	0.204
3		3546	199	705.2	28.2	0.199
4		3618	199	705.2	28.2	0.195
5		3636	199	705.2	28.2	0.194
6		3636	199	705.2	28.2	0.194
7		3600	199	705.2	28.2	0.196
8		3564	199	705.2	28.2	0.198
9		3510	199	705.2	28.2	0.201
10		3438	199	705.2	28.2	0.205
11		3384	198	705.2	28.1	0.208
12	P5P4P1	3663	218	834.7	26.1	0.228
13		3604	217	834.7	26	0.232
14		3544	216	834.7	25.9	0.236
15		3505	216	834.7	25.9	0.238
16		3465	215	834.7	25.8	0.241
17		3445	215	834.7	25.8	0.242
18		3445	215	834.7	25.8	0.242
19		3425	215	834.7	25.8	0.244
20		3445	215	834.7	25.8	0.242
21		3445	215	834.7	25.8	0.242
22		3445	215	834.7	25.8	0.242
23		3465	215	834.7	25.8	0.241
24	P5P4P1	3132	196	705.2	27.8	0.225
Optimize results		SUM			Calculation	
		83,710	4,969	18,478	27	0.221
The current operation output		89,524	5,342	19977	26.7	0.223
difference		-5814	373	-1499	0.3	-0.002

Usually the lifetime span of pumps is set at about 10 years and after that, in the long term, 10 years, their efficiencies will decrease significantly unless a good maintenance regime is applied. In all, this saving is expected to support the purchasing of new units. This saving will decrease their LCC by 5% annually.

5. Conclusions

This paper presents a way to decrease the operational costs of conventional WTP by optimizing energy management factors by optimizing pump operation schedules at no cost. It was applied for the January and July months of modeling of the WTP outputs as it reflected pump system behaviors over the winter and summer, respectively. It will expected to reduce the operational cost of the pump systems by apply this optimize schedule over the year as in the results and discussion section by 177,360 EGP.

On the other hand, this manuscript allows us to discuss more energy-saving potentials based on improving the pumps efficiencies through maintenance or renewal, as if we replace the lowest efficient unit pump 5 with an overall efficiency of 48% with a high efficiency that can reach 76% this day, we can increase this saving by 86,000 kwh.

Finally, the genetic algorithm is achieving the optimal solution, but with some concerns as the final solution has an effect on production by a percentage of 1.4:6.5%. Put simply, the optimizer has been a success because it improves the overall efficiency of the pump system and decreases specific energy consumption, so overall, the optimized solution may act as a good schedule operation for most of January and some days in July, and it needs to be developed with other algorithms for continuous improvement. Furthermore, the research proves that the modeling of the WTP output in flow and pressure acts as a good solution in many developing countries to reduce the cost of extending the pressure meters in many nodes of the water networks. Also, the other O&M factors can be added as optimization objectives to generate a sustainable operation plan, like pump maintenance times, and balance the total operation times between the pumps.

Abbreviations

Abbreviations	Definitions
AEFA	artificial electric field algorithm
BFPSO	hybrid butterfly-particle swarm Optimization
GA	genetic algorithm
LCC	the life cycle cost
O&M	The operating and maintenance
PH	The pump output hydraulic energy -Kwh
PSO	particle swarm optimization
SEC	the specific energy consumption - kwh /M^3
WTP	water treatment plant

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