Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 15(7): 23-34, December 2021

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Development of optimal pump schedules for improved energy efficiency in water supply systems (case of NWSC)

Samuel KIKOMEKO[1*] and Jotham SEMPEWO[2]

[1] *National Water and Sewerage Corporation, Uganda.*
[2] *College of Engineering, Design Art and Technology, Department of Civil and Environmental Engineering, Makerere University, Uganda.*
[*] *Corresponding author; E-mail: samuel.kikomeko@nwsc.co.ug*

Received: 11-08-2020 Accepted: 03-09-2021 Published: 30-12-2021

ABSTRACT

The water utility in Uganda (NWSC) was under pressure from regulators, environmentalists and board members to reduce energy costs. However, achieving energy efficiency in the water distribution systems of Kampala that is characterized by variable demands and prescribed pressures would be impossible if this utility continued operating on trial and error methods. This research was undertaken in the year 2016-2017 and aimed at exploring how pump schedule optimization could enable NWSC to deal with the challenge of high energy costs and improve water utility performance. In this research, the energy consumption of existing pumps was obtained from historical data, data was diagnosed and based on the diagnostic findings, decision variables were selected and optimal pump schedules were formulated. The formulated schedules were applied to the Gabba Muyenga supply system of National Water and Sewerage Company (Uganda) as a proof of concept. The formulated pump schedules when applied on different pumps classified as models 1, 2 and 3 based on pump flow ratings and motor voltage ratings, results show that scheduling pump operations based on time of the day tariffs enabled NWSC to save about 0.373 Million kWh annually. On the other hand pump scheduling based on pressure, modulation had the potential to reduce water losses enabling NWSC to save 12 m^3/hr equivalent to 0.068 million kWh per year in energy terms without compromising customer service levels and this was only for the established DMA within the case study area and not for the entire NWSC water distribution network. The data presented were obtained through field measurements, statistical analysis and hydraulic design calculations.

Keywords: DMA (District Metered Area), NWSC (National Water and Sewerage Corporation), Gabba Muyenga Supply system, SD (Scheduling Decisions).

INTRODUCTION

The Government of Uganda is promoting energy efficiency in recognition of the benefits among which is energy savings associated with the reduction of electricity consumption for the existing consumers and availing this to meet the incremental demand which would otherwise have to be met by investment. However, reducing energy consumption is one of the global challenges across all sectors and water utilities are not an exception, therefore, water utilities in developing countries have started to investigate the integration of online telemetry and optimal

DOI : https://dx.doi.org/10.4314/ijbcs.v15i7.3S
Special issue; AfWA congress

control systems to reduce the operating costs. Energy costs for pumping often represent 25-30% of a utility's total operation and maintenance (O&M) costs and also represent the largest proportion of the controllable cost of providing water Savic et al. (1997). In Kampala water, the current total monthly energy consumption for the Gabba Muyenga supply area ranges between 5 million to 5.5 million Kilo Watt Hour (KWH) with the maximum Kilo Volt Ampere (KVA) registered to be in the range of 3500KVA. In 2008, the pumping energy cost accounted for 55% of the total operating expenditure (Mutikanga, 2008), with the increasing global change (population growth, urbanization, climate change & improved living standards), water utilities will even face more difficulties in meeting the energy required to supply water for the increased demand. An increase in demand for energy to move and treat water and wastewater in Kampala is likely to be significant in the next 20 years or so due to stricter health and pollution regulations, which often require additional or more sophisticated treatment that uses more energy. This will progressively increase and affect the corporation’s operating margin as well as the ability to and goal of providing funds for service expansion. Therefore, the questions are (1) can the same amount of water be supplied at cheaper energy costs? Or (2) can the same amount of energy be used to supply an increasing demand?

Since energy costs depend on energy usage and the energy rate, to provide a solution to the questions above, (1) pump schedules have to be structured to promote off-peak energy usage with lower rates. However, scheduling of WDS operation in developing countries is such a complex task and consists of applying cost-saving measures whilst aiming at satisfying various constraints on the system. In this study, the most significant savings were made by concentrating the highest power pumping during the night, when electricity is least expensive, and running the variable speed pumps at their maximum efficiency. This led to filling the reservoirs over the night and later emptied during the day, thus reducing the amount of pumping required during peak hours and meeting consumer demand. (2) On the other hand, the need to ensure that reservoirs are maintained at a minimum level for service reliability and the need to minimize wear and tear on pumps due to pump switching meant that identification of suitable optimized pump operation was a complex task that couldn’t be solved based on experience and rule of thumb. Moreover, the fact that the water networks had grown organically into spaghetti networks, nonlinear and counterintuitive meant that obtaining an optimal solution was an elusive exercise. As a result, improving energy efficiency through optimal pump scheduling in water supply systems was required.

MATERIALS AND METHODS

The comparative data analysis methodology proposed by Arregui et al. (2013) which rely on existing data and not on costly fieldwork and statistical studies was the basis of the research. Statistical sampling tools (stratified random sampling) and regression analysis techniques were applied to grouped pumps to determine sample sizes and pump operational efficiencies respectively. The research methodology was implemented in four steps in tandem with the stated research objectives, and these included:

(i) Diagnosing the performance of existing booster pumps concerning energy to identify potential for improvement of energy efficiency through pump schedule optimization.
(ii) Formulation of pump optimization schedules for improved energy efficiency.
(iii) Application of formulated schedules on a real case study network and comparison of the impact of the implementation of the proposed pump scheduling routine on energy costs.

Diagnosis of pumps concerning Energy Efficiency

Kampala Water Distribution Supply network consisted of three supply systems namely; Gabba-Muyenga, Gabba-Gunhill and Gabba- Naguru supply system. To diagnose the performance of existing pumps the study focused on the Gabba-Muyenga water supply system simply because it consists of many pumping stations and accounts for about 88% of the total water supplied to the Kampala metropolitan area. Three different pump models were examined based on volumes pumped (m^3/hr) and this was so because the energy consumed by pumps varies markedly with this parameter (Walski et al., 2003). The pump models formed were (3–300) m^3/hr model 3, (301–800) m^3/hr model 2, and above 801 m^3/hr model 1. The voltage ratings for the respective models were 215V, 400V and 3300V respectively.

Sampling and stratification of pumps

In the sampling of the pumps, asset management data which included delivery heads (m), monthly energy consumptions (kWh) and monthly pumped volumes (m^3) were taken from the utility's database, the pumps were grouped based on water pumped per hour to build more homogenous groups and reduce variability associated with sampling. The sample size was selected according to the research advisors (2006), sample size table recommendations at 95% confidence level considering a 2.5% margin of error for each sub-stratum to have a more reliable statistical judgment derived from sample collection. Analysis of energy use efficiency based on scheduling was based on these sampled pumps to develop optimal schedules for improved energy use.

Analysis of pump data

Carrying out pump operational diagnosis was considered the first critical step in the development of schedules for improved energy use; this was because of the need to quantify the current level of energy use efficiency that would later be used as a benchmark for improvement.

The starting point of the diagnosis was to select samples of pumps for each model considered in this study, to select the samples; a database of pumps' operational records for the years 2012-2015 was obtained from the utility's database. This database consisted of 79 pumps. Of which 17 (21.5%) were model 1 pumps, 12 (15.2%) were model 2 pumps and 50 (63.3%) were model 3 pumps. All pumps considered in this study were fixed speed high-level pumps; it is from these pumps in the database that samples for each model were selected using the equation by *Arreguin-Cortes and Ochoa-Alejo, 1997.* Table 1 shows the number of pumps that were selected and used per model in this study.

The next step was to assess whether pump scheduling impacts the total energy costs (UGX) and specific energy costs (UGX/kWh). From the collected data, the total consumption used at off-peak, shoulder and peak tariff ranges were obtained by summing up the individual pump consumptions in the tariff ranges that fall in the respective categories. This was done separately for each pump strata because each model has got different tariff rates for off-peak, shoulder and peak ranges during the day. Having realized the impact of tariff periods on specific energy costs (UGX/kWh) for each pump model based on historical data, the next step was to use the data to identify the efficiency at which these pumps were operating by considering the specific energy consumption (kWh/m^3). The objective was to identify if any physical operational constraints could be resulting in energy use inefficiencies. The resultant model took the form of the equation.

$Y = \beta_0 + \beta_1 x$ Where Y was the totalized power consumed, X was the totalized water pumped, and $\beta_j (j = 0,1)$ the regression coefficients.

$D = (\beta_1 * 100)$ Equation (4.2) was used to determine the percentage of energy efficiency.

Table 1: Samples considered after screening data.

Pump models	Pumps considered after screening
Model 1	4
Model 2	3
Model 3	11

RESULTS

Based on the time of the day energy use, it was realized that the significant difference in specific energy cost (UGX/kWh) between the periods analyzed was due to lower off-peak energy consumption for the period 06^{th}/11/2012 to 07^{th}/10/2013 compared to the year 7/11/2013 to 08^{th}/10/2014 as detailed in Table 2. Based on these findings it was therefore realized that by rescheduling some of the runnings of model 1 pumps to more off-peak periods, the specific energy cost could be reduced hence improving energy efficiency.

As detailed in Table 3, by Comparing percentages of energy utilization during various tariff periods between model 1 and model 2 for the same periods of analysis, it was also realized that model 1 off-peak energy utilization was less than model 2 off-peak energy utilization and for this reason, the specific energy cost (UGX/kWh) for model 1 pumps were higher than that of model 2 for both periods of analysis.

Also as shown in Table 4, the unit energy cost for model 3 pumps could further be reduced by having more pumps run during the off-peak tariff period if there is adequate storage & supportive system at upstream & downstream sides of the network

Modelling for pump efficiency determination

Model 1 output

Using the operational records for the period 6^{th}-11-2012 to 8^{th}-10-2014 for only model 1 pumps, a regression relationship was developed between power consumed (kWh) and water pumped (m^3). From the results, the specific energy consumption (kWh/m^3) of model 1 high lift pumps detailed in Figure 1 was found to be satisfactory i.e. Energy Efficiency rate of model 1=74.2% for a four combination; however, the goodness of fit of the regression line which is measured using the coefficient of determination (R^2 = 68.1%) was rather low and this is a result of the drop in efficiency as the number of pump combination increased. This was an indication of low output and increased system resistance thus implying that energy costs will increase if more pumps are engaged and the output flow will not necessarily increase.

Model 2 output

Using the operational records for the period 6^{th}-11-2012 to 8^{th}-10-2014 for only model 2 pumps, a regression relationship Figure 2 was developed between power consumed (kWh) and water pumped (m^3). The specific energy consumption (kWh/m^3) of model 2 high lift pumps was high i.e. Energy Efficiency rate of model 2=87.2% for only two pumps in operation. This efficiency rate for model 2 pumps was attributable to the low output of the pumps resulting from a mismatch between the suction and delivery pipe sizes.

Model 3 output

Using the water production and power consumption records for the period 01-12-2014 to 30-12- 2014 for model 3 pumps, a regression relationship Figure 3 was developed between power consumed (kWh) and water pumped (m^3). The results from linear regression relationship could not provide a single uniform efficiency rate for all sampled model 3 pumps, this implied that scheduling based on time of the day tariff and network re-modifications for improved (kWh/m^3) could only apply to individual stations, based on this background pressure controls were allocated in the network by considering the water demand required by users firstly as deterministic and subsequently as probabilistic. These controls were used to trigger pumps on and off.

Impact of scheduling on energy costs and efficiency

To assess the impact of scheduling on model one pumps, the operating costs of the selected pumps based on the Ugandan energy tariff structure was developed as detailed in Table 5, the respective output (m^3) and energy consumptions (kW) for various pump combinations were also computed as shown in Figure 6. To develop an optimized schedule, the operating staff were requested to provide details on how they operated pumps on 28^{th} January 2015 as a benchmark case for the analysis, Table 7 represents the output per day based on the number of operating hours on that day. Using the developed energy optimization tool Figure 5, an optimized scheduled detailed in Table 8 was developed and this was the appropriate schedule to ensure maximized output at a reduced cost.

It was realized that due to changes in operating hours of different pump combinations there is an additional output of 549 m^3 per day (1%) and a reduction in energy consumption by UGX 59,060 per day. Snapshots of the energy decision support tool are shown in Figure 5.

Impact of model 2 optimal scheduling operations on energy costs

Findings from the diagnosis showed that model 2 pumps were optimally scheduled concerning specific energy costs (UGX/kWh) however the specific energy consumption (kWh/m^3) which is an indicator of system efficiency was high this prompted for detailed efficiency tests. Operational parameters such as delivery head and valve position were monitored to identify the potential for energy conservation measures. From field assessment, it was realized that the delivery pressure of model 2 pumps was controlled to match the rated current of the motor as represented in Figure 4.

Because of the constriction represented in Figure 4, the operating head was 104 m for single operation of pumps and around 112 m for parallel operation of pumps yet the rated head of the pumps was115 m each. Further still, the monitored head after the delivery valve at the pressure vessel was around 92 m representing a pressure loss of around 12 – 23 m depending on the single operation and parallel operation of pumps. It is because of these significant pressure drops that only two pumps were considered for analysis instead of the three pumps that were recommended.

Maintaining the same scheduling protocol because of the low specific energy costs (UGX/kWh) and replacing model 2 pumps with new suitable sized pumps of 95 m head or for the existing pumps changing the delivery pipe size to 600 mm diameter are the recommended solutions to improving energy efficiency the former being preferred because of the cost of implementation.

Impact of model 3 optimal scheduling operations on energy costs

To formulate optimal pump operational protocols, fixed outlet control settings were established, pressure sensors were introduced to control outlet pressure, in automation mode the pump was triggered off any time the system pressure exceeded 56m. The results derived directly from 24-hour simulation runs after pressure reduction is in Table 9. The primary criterion was to ensure the availability of flow at all nodes, throughout the DMA at all times, including the maximum consumption periods. The water and energy saving predictions relied heavily on the accuracy of data before and after the implementation of schedules based on pressure management. Most of the cost parameters were estimated. It is anticipated that the developed schedule acted as a stimulus to promote the use of pressure management strategies as part of the broader energy management policy in water utilities.

Table 2: Model 1 Energy Consumption based on time of the day tariff.

Year	Electricity Consumed (Million kWh)				Amount (UGX, Million)	Cost of Energy per unit (UGX/kWh)
	Shoulder (R1)	Peak (R2)	Off-Peak (R3)	Total		
07/11/2013 to 08/10/2014	5.5 (29%)	4.81 (26%)	8.49 (45%)	18.796	4144.11	220.48
06/11/2012 to 07/10/2013	8.24(48%)	4.63 (27%)	4.14 (24%)	17.006	3949.67	232.25

Table 3: Model 2 Energy Consumption based on time of the day tariff.

Year	Electricity Consumed (Million kWh)				Amount (UGX, Million)	Cost of Energy per unit (UGX/kWh)
	Shoulder (R1)	Peak (R2)	Off-Peak (R3)	Total		
07/11/2013 to 08/10/2014	3.09 (25%)	3.17 (25%)	6.18 (50%)	12.433	2728.10	219.41
06/11/2012 to 07/10/2013	2.17(27%)	2.01 (25%)	3.81 (48%)	7.99	1731.32	216.69

Table 4: Model 3 Energy Consumption based on time of the day tariff.

Station Total	Shoulder Tariff	Off peak tariff	Peak tariff	Fuel	Total Cost (UGX)	Volumes (m3)	SHs/M^3	kWh/ m3	kWh
Station 1	55% (9.9hrs)	23% (1.38hrs)	22% (1.32hrs)	420	19450676	50786	382.99	0.7438	37775
Station 2	49% (8.8hrs)	25% (1.5hrs)	26% (1.6hrs)	700	8462445	20640	410	0.6307	13019
Station 3	54% (9.7hrs)9+	21% (1.26hrs)	25% (1.5hrs)	720	13587938	31670	429.05	0.7483	23699
Station 4	79% (14.22hrs)	11% (0.66hrs)	10% (0.6hrs)	60	2725463	14379	189.54	0.3639	5233
Station 5	44% (7.92 hrs.)	26% (1.56hrs)	30% (1.8hrs)	0	17632847	58657	300.61	0.6364	37331
Station 6	49% (8.82hrs)	23% (1.38hrs)	29% (1.7hrs)	260	7570784	20485	369.58	0.6963	14264
Station 7	48% (8.64hrs)	26% (1.56hrs)	26% (1.6hrs)	80	6517657	22566	288.83	0.5826	13148
Station 8	51% (9.18hrs)	23% (1.38hrs)	26% (1.6hrs)	400	11068286	31136	355.48	0.6616	20600
Station 9	73% (13.14hrs)	10% (0.6hrs)	17% (1.0hrs)	800	4572992	15099	302.87	0.2743	4142
Station 10	76% (13.68hrs)	14% (0.84hrs)	10% (0.6hrs)	0	1555659	4960	313.64	0.6461	3205
Station 11	71% (12.78hrs)	24% (1.44hrs)	5% (0.3hrs)	0	1727369	4724	365.66	0.7356	3475
Total	52% (9.36hrs)	23% (1.38hrs)	25% (1.5hrs)	3440	94872115	275102	3708.248	0.6393	175891

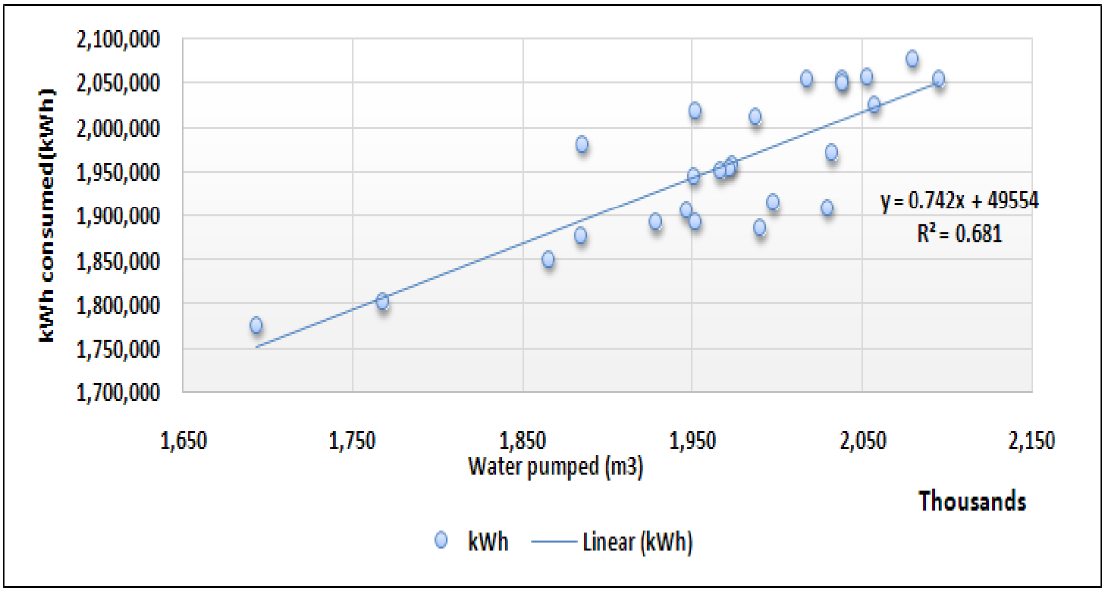


Figure 1: Energy Efficiency rate of model 1.

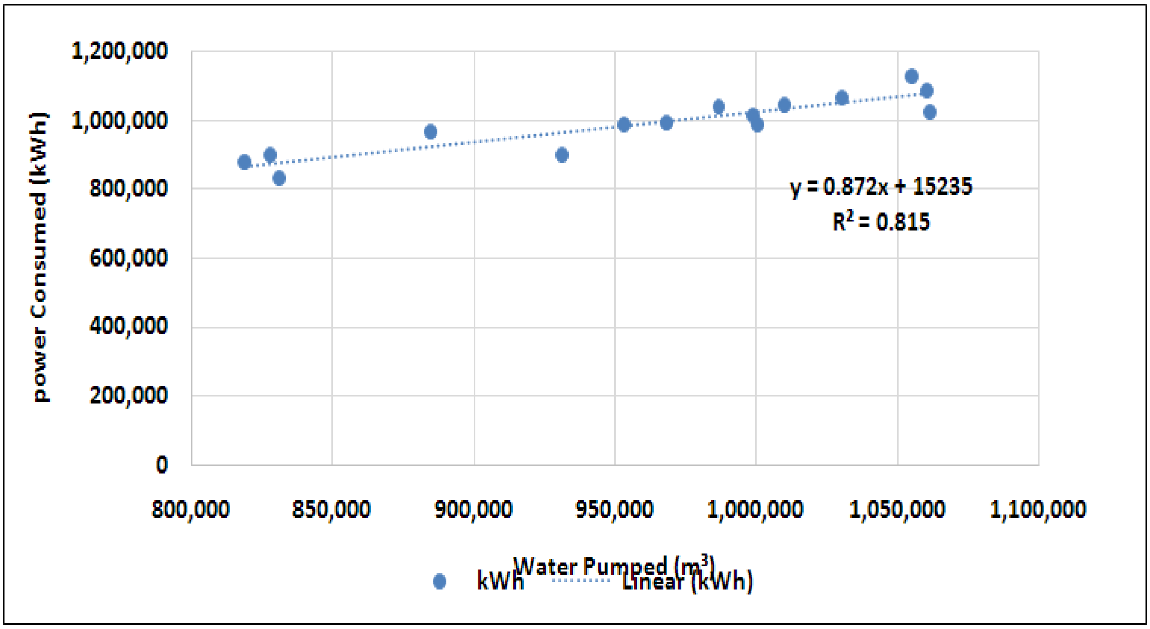


Figure 2: Energy Efficiency rate of model 2.

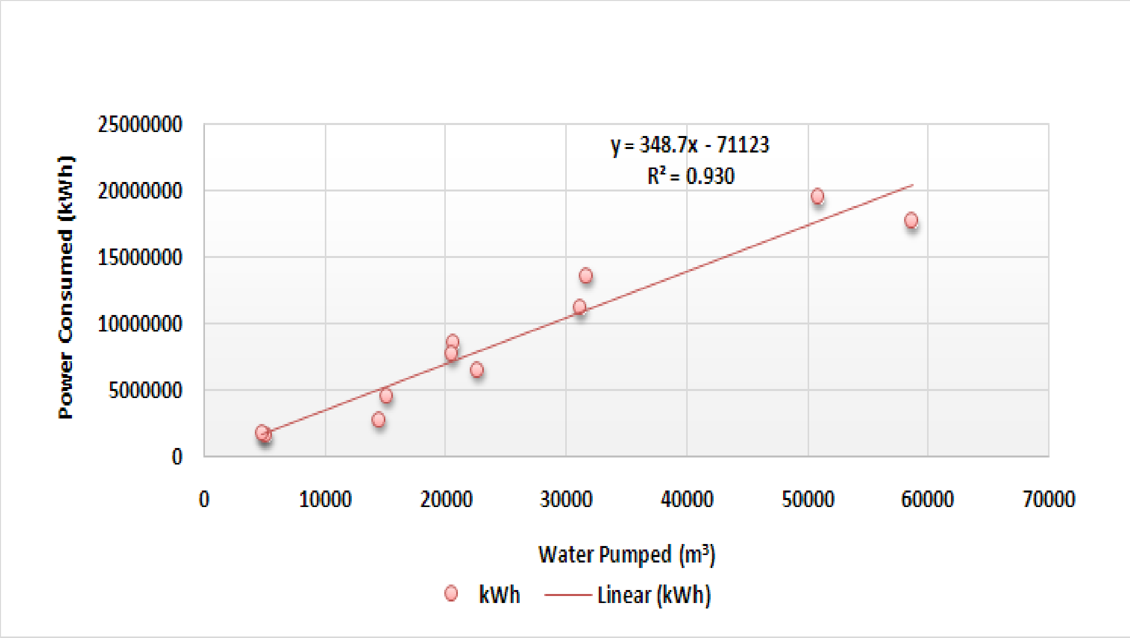


Figure 3: Energy Efficiency rate of model 3.

Table 5: Operating cost of pumps based on tariff structure.

Tariff	Operating Cost in 000'UGX/hr		
	Operation of 2 pumps in parallel	Operation of 3 pumps in parallel	Operation of 4 pumps in parallel
Shoulder	214.861	307.549	394.351
Peak	266.151	380.965	488.488
Off-Peak	150.860	215.939	276.885

Table 6: Details of Output and energy per day.

Measured parameters	Operation of 2 pumps in parallel	Operation of 3 pumps in parallel	Operation of 4 pumps in parallel
The output of pumps,m^3/hr	1788	2454	2925
Power consumption, kW	1115	1596	2046

Table 7: Cost and output per day based on number of operating hours (as of 28th January 2015).

Present Scenario				
Tariff	**shoulder**	**Peak**	**Off peak**	**Total**
Operation of 2 pumps in parallel (hrs.)		6		6
Operation of 3 pumps in parallel (hrs.)	11		6	17
Operation of 4 pumps in parallel (hrs.)	1			1
Output per day, m^3	29919	10726	14724	55369
Energy per day, kWh	19602	6690	9576	35868
Total Cost per day, UGX	3777392	1596903	1295633	6669928

Table 8: Optimized schedule (cost and output per day based on number of operating hours).

Developed optimization schedule				
Tariff	**Shoulder**	**Peak**	**Off peak**	**Total**
Operation of 2 pumps in parallel (hrs.)	2	6		8
Operation of 3 pumps in parallel (hrs.)	10			10
Operation of 4 pumps in parallel (hrs.)			6	6
Output per day, m^3	25662	10726	19531	55918
Energy per day, kWh	16594	6690	13424	36708
Total Cost per day, UGX	3197664	1596903	1816301	6610868

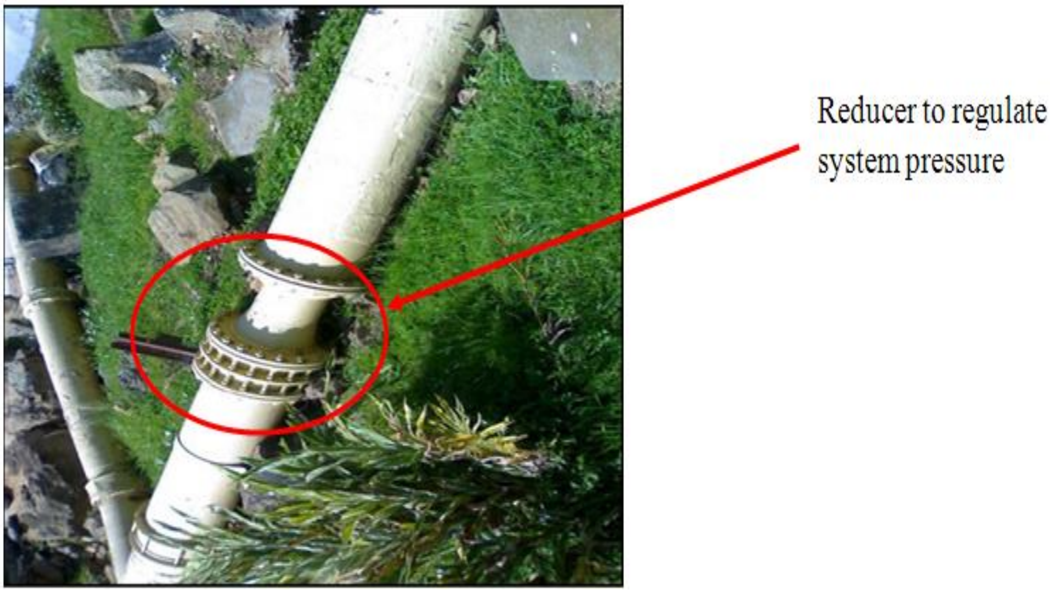
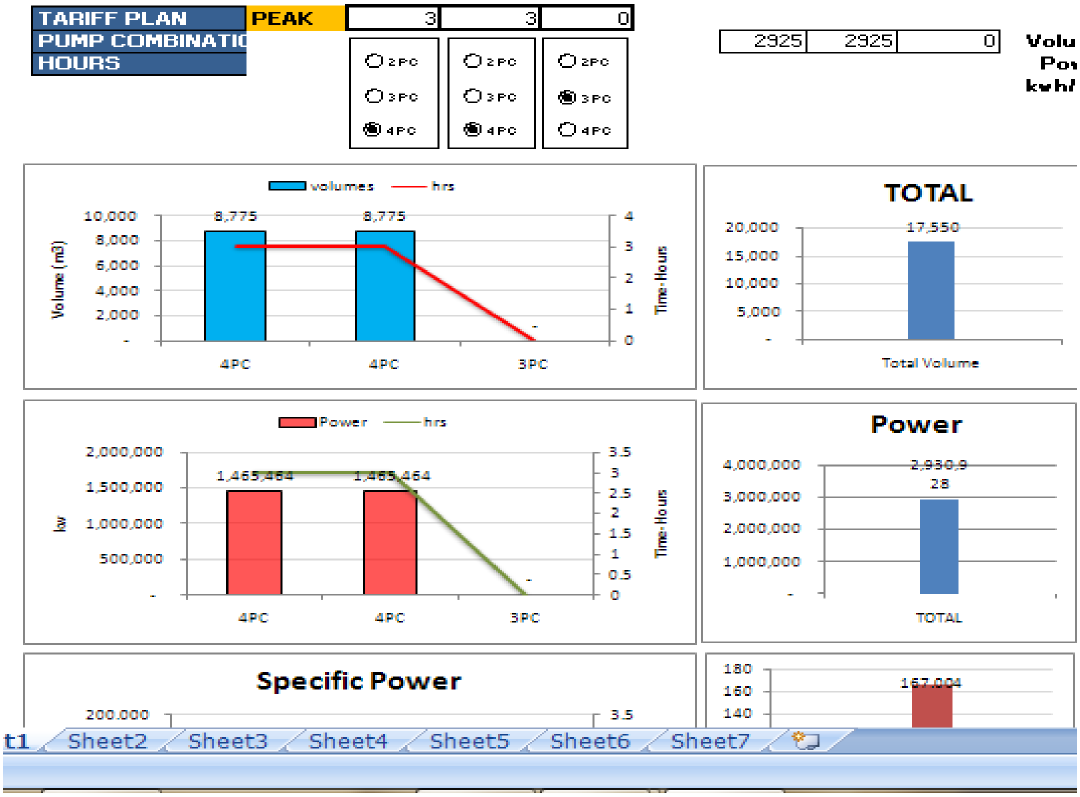


Figure 4: Energy Reducer to regulate system pressure for model 2 pumps.

Table 9: The results derived directly from 24-hour simulation runs after pressure reduction.

Hour	DMA Inflow (m3 /hr) Before PM	DMA Inflow (m3 /hr) After PM	Water savings(m3 /hr)	Energy savings in water Pumpage (kWh)
0-1.	88.704	65.844	22.86	14.0194436
1-2.	89.496	66.42	23.076	14.1519108
2-3.	91.692	66.384	25.308	15.5207384
3-4.	93.276	67.536	25.74	15.7856728
4-5.	93.384	67.572	25.812	215.8298285
5-6.	89.496	67.14	22.356	13.7103535
6-7.	81.072	64.584	16.488	10.1116617
7-8.	59.544	55.26	4.284	2.62726582
8-9.	51.84	50.148	1.692	1.03765961
9-10.	51.624	50.184	1.44	0.88311456
10-11.	53.136	51.408	1.728	1.05973747
11-12.	56.808	52.92	3.888	2.38440931
12-13.	57.672	53.676	3.996	2.4506429
13-14.	62.892	56.088	6.804	4.1727163
14-15.	66.204	57.816	8.388	5.14414231
15-16.	69.984	59.868	10.116	6.20387978
16-17.	67.644	58.428	9.216	5.65193318
17-18.	68.22	58.968	9.252	5.67401105
18-19.	62.856	55.512	7.344	4.50388426
19-20.	60.372	53.964	6.408	3.92985979
20-21.	68.652	59.076	9.576	5.87271182
21-22	77.868	61.056	16.812	10.3103625
22-23	80.208	62.064	18.144	11.1272435
23-24	84.06	63.432	20.628	12.6506161
Daily Mean ($\bar{x}.$)	71.95	59.4	12.564 m³/hr	185kWh
Standard deviation (s)	14.3	5.8		



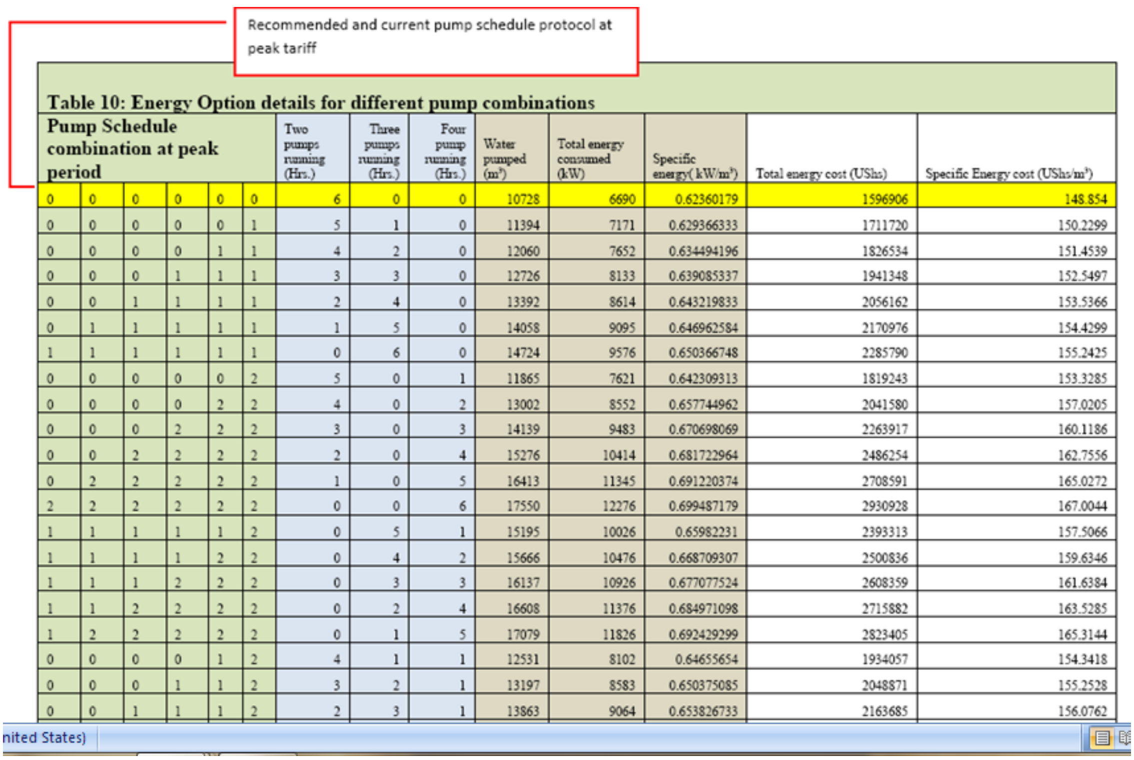

Recommended and current pump schedule protocol at peak tariff

Table 10: Energy Option details for different pump combinations

Pump Schedule combination at peak period						Two pumps running (Hrs.)	Three pumps running (Hrs.)	Four pump running (Hrs.)	Water pumped (m³)	Total energy consumed (kW)	Specific energy(kW/m³)	Total energy cost (UShs)	Specific Energy cost (UShs/m³)
0	0	0	0	0	0	6	0	0	10728	6690	0.62360179	1596906	148.854
0	0	0	0	0	1	5	1	0	11394	7171	0.629366333	1711720	150.2299
0	0	0	0	1	1	4	2	0	12060	7652	0.634494196	1826534	151.4539
0	0	0	1	1	1	3	3	0	12726	8133	0.639085337	1941348	152.5497
0	0	1	1	1	1	2	4	0	13392	8614	0.643219833	2056162	153.5366
0	1	1	1	1	1	1	5	0	14058	9095	0.646962584	2170976	154.4299
1	1	1	1	1	1	0	6	0	14724	9576	0.650366748	2285790	155.2425
0	0	0	0	0	2	5	0	1	11865	7621	0.642309313	1819243	153.3285
0	0	0	0	2	2	4	0	2	13002	8552	0.657744962	2041580	157.0205
0	0	0	2	2	2	3	0	3	14139	9483	0.670698069	2263917	160.1186
0	0	2	2	2	2	2	0	4	15276	10414	0.681722964	2486254	162.7556
0	2	2	2	2	2	1	0	5	16413	11345	0.691220374	2708591	165.0272
2	2	2	2	2	2	0	0	6	17550	12276	0.699487179	2930928	167.0044
1	1	1	1	1	2	0	5	1	15195	10026	0.65982231	2393313	157.5066
1	1	1	1	2	2	0	4	2	15666	10476	0.668709307	2500836	159.6346
1	1	1	2	2	2	0	3	3	16137	10926	0.677077524	2608359	161.6384
1	1	2	2	2	2	0	2	4	16608	11376	0.684971098	2715882	163.5285
1	2	2	2	2	2	0	1	5	17079	11826	0.692429299	2823405	165.3144
0	0	0	0	1	2	4	1	1	12531	8102	0.64655654	1934057	154.3418
0	0	0	1	1	2	3	2	1	13197	8583	0.650375085	2048871	155.2528
0	0	1	1	1	2	2	3	1	13863	9064	0.653826733	2163685	156.0762

nited States)

Figure 5: Snapshots of the energy decision support.

DISCUSSION

Power savings are predominantly from shifting pumping from high day tariffs to lower night tariffs. It is estimated that energy savings for the first twelve months of operating four models 1 pump in parallel were approximately UGX 20.35million. This amounted to approximately 10 per cent of the energy bill and in energy; terms represent a saving of 0.0348Million kWh

I. Assessment and comparison of pumping cost per unit of water i.e. UGX/000'm^3 and kWh/000'm^3 indicate the level of efficiency of the subsystem and system on a whole. In the absence of such monitoring/measuring tools, the operational and maintenance (O&M) personnel are handicapped to further improvement options for energy efficiency.

II. Suitable pump sizing results in significant energy savings, in this study resizing model 2high lift pumps, represented energy-saving benefits of about 0.338 million kWh, In financial terms at UGX 220.7/kWh: UGX 74.6 Million can be realized, however resizing pumps involves incurring investment costs. In this study, an estimated UGX 250 Million for three Pumps was calculated. Simple payback period analysis indicated that the cost could be recovered in about 4 years

III. Significant energy cost savings can be obtained by introducing pressure management, lowering average network pressure in the network by 7 from 63 m to 56 m reduced leakage by about 5 % of its original value. The fixed-outlet pressure settings were considered more appropriate for water utilities in the countries that are just starting to work with pressure modulation systems. They are relatively cheap in terms of investment cost and easy to operate and maintain. It is predicted that further reductions could be realized in future by adopting "intelligent" PM.

Conclusion

It is recommended to optimize operation of pumps utilizing time of the day tariff so as to save the operating cost. It is recommended to implement intelligent pressure management using optimization techniques to maximize pressure reductions without compromising customer service levels. It is recommended to install suitable sized pumps for operations, during this study it was observed that for model 2 pumps the actual head required for pumping was around 90 m whereas the rated pump head was 115 m. Mismatch in head by 25mexisted which resulted for pumps to operate in throttled condition. Therefore, pumps operating with throttled valves should be replaced with suitable sized pumps; this will result in energy savings.

REFERENCES

Abdel Meguid, Ulanicki B. 2011. Pressure and Leakage Management in Water Distribution Systems via Flow Modulation PRVs. Water Distribution Systems Analysis 2010: pp. 1124-1139.

Ilemobade AA, Manson NJ, Stephenson D. 2005. Pump and reservoir system operational optimization using a non-linear tool. *Journal of the South African Institute of Civil Engineering,* **47**(4): 2-11.

Kazantzis MD, Simpson AR, Kwong D, Tan SM. 2002. A new methodology for optimizing the daily operations of a pumping plant. In: Proceedings of 2002 Conference on Water Resources Planning. Roanoke, USA: ASCE.

Lansey KE, Awumah K. 1994. Optimal pump operations considering pump switches. *Journal of Water Resources Planning and Management, ASCE,* **120** (1): 17–35.

Mutikanga HE, Sharma S, Vairavamoorthy K. 2009. Water Loss Management in Developing Countries: Challenges and Prospects. *Journal AWWA,* **101**(12): 57-68.

Nitivattananon V, Sadowski EC, Quimpo RG. 1996. Optimization of water supply system operation. *Journal of Water Resources Planning and Management, ASCE,* **122** (5): 374–384.

Goldman FE, Mays LW. 2000. The application of simulated annealing to the optimal operation of water systems. In: Proceedings of 26th Annual Water Resources Planning and Management Conference. Tempe, USA: ASCE.

Ormsbee LE, Lansey KE. 1994. Optimal control of water supply pumping systems. *Journal of Water Resources Planning and Management, ASCE,* **120** (2): 237–252.