Using Variable Speed Control on Pump Application

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Abstract

Pumps are one of the most common variable speed drive (VSD) system applications and special interest has focused on improving their energy efficiency by using variable speed control instead of throttling or other less efficient flow control methods. Pumps are the single largest user of electricity in industry in the European Union, consuming 160 TWh per annum of electricity and accounting for 79 million tonnes of carbon dioxide (CO2) emissions [1]. Centrifugal pumps are the most likely pump style to provide a favorable return based on energy savings when applied with a variable speed drive. To help illustrate this, are conducted benchmark testing to document various head and flow scenarios and their corresponding effect on energy savings. Paper shows the relationship of static and friction head in the energy efficiency equation and the effect of motor, pump and VSD efficiencies. The received results are good reference points for engineers and managers of water sector in Albania to select the best prospects for maximizing efficiency and energy savings.

Key-words*: efficiency, pump, energy saving, efficient drive*

1. Introduction

Albania's water resources are a national asset, with hydropower from the rivers currently providing about 99 percent of domestic electricity. As climate change mitigation targets and legislation are tightened, and with other countries struggling to reduce their greenhouse gas emissions, Albania's green production capability is an increasingly important national and regional asset. However, such a high dependence on hydropower also brings challenges. Albania finds it difficult to meet energy demand and maintain energy supply, fig. 1. The country's rainfall, on which its hydropower depends, is among the most variable in Europe. Hydropower production varies between about 2,900GWh in very dry years to twice that amount in very wet years, [2].

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Also, Albania has limited regional electricity interconnections at present, and imports are expensive. There are also significant inefficiencies in domestic energy supply, demand and water use. From 10 percent to 20 percent of water resources are lost in the irrigation system [2].

Albania's recent draft National Energy Strategy (NES) sets out a so-called active scenario, which aims to improve energy security. The draft NES active scenario also emphasizes the need for improved energy efficiency through greater use of domestic solar water heating, improved building standards, lower-energy appliances, high efficiency drive and alternative heating sources other than electricity.

There are enormous opportunities for Albania to close its supply–demand gap through improved energy efficiency and demand-side management [3]. While this is recognized in the draft NES active scenario, more emphasis and progress could be made on this issue.

It is often more cost effective to invest in end-user energy efficiency improvement than in increasing energy supply to satisfy demand for energy services. Efficiency improvement has a positive effect on energy security, local and regional air pollution reduction and employment. The best kWh is the one that is saved. In other words, the Albanian economy will consume less energy to produce the same output unit becoming more competitive and gaining more markets, creating more jobs and providing a higher welfare.

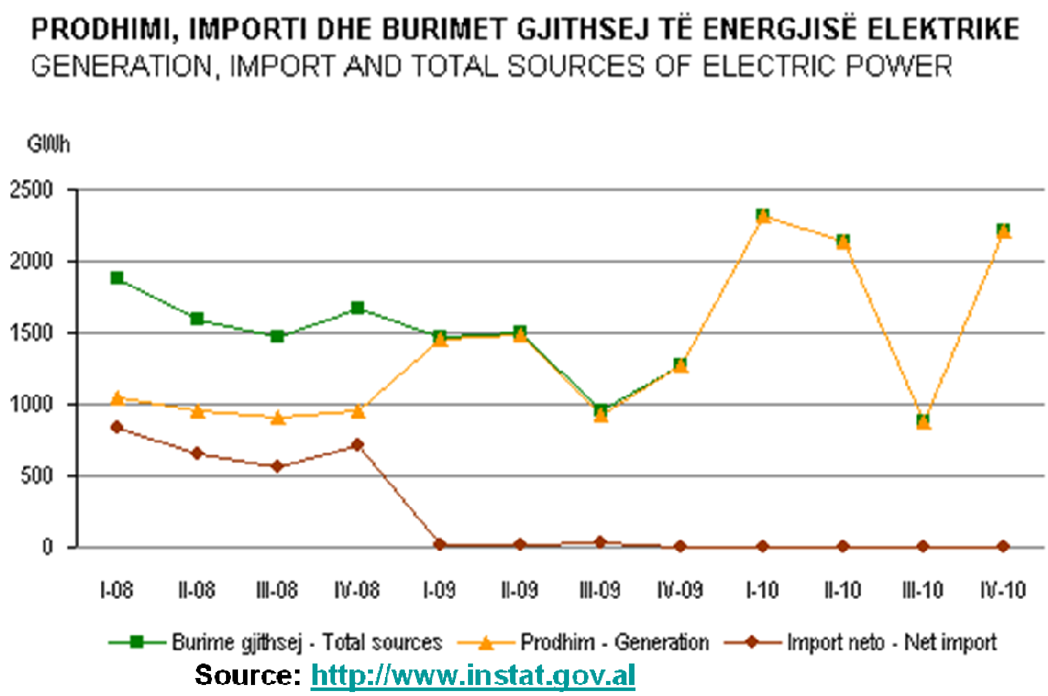


Fig. 1. Generation, Import and Total Sources of Electric Power [4]

This paper deals with energy conservation by using variable speed control on pump application instead of fixed speed pumping systems where the regulation of flow is done through throttling valve.

This transition becomes a necessity as a direct result of limitation in energy sources and escalating energy prices. In the end of this analysis there are different practical cases in where variable speed drive are compared with fixed speed drive. In all these cases energy savings can be achieved and the simple payback is less of three years. So, it is very interesting the implementation of variable speed drive on pumping systems.

2. Performance of water sector in Albania

Water sector in Albania is a very important sector through which provided drinking water supply of the population. In Albania, in recent years there have been significant improvements in water service given its importance in human health and the environment. Albanian government funds on water and sanitation have increased five times since 2000, but nearly half of these costs goes to cover operating costs and not for investment. Around 50% of operational costs account for the costs of water supply for electricity. Fig. 2, [5] shows clear the high cost of energy in total cost needed to produce water for all water supply and sanitation companies in Albania for last year. The high cost of electricity on total cost of water has done that water supply and sanitation companies in Albania to be the worst debtors of CEZ Distribution. It is done improvements in this directions as shown on table 1 but again they can cover only 56% of total operational costs from their incomes.

Table1. Performance of water supply companies

Performance indicator	**2009**	**2010**
Covering of operational costs	39.50%	56%

So, CEZ distribution company was obligated to interrupt the supply with electricity for several water supply and sanitation companies during the summer 2011. *CEZ Distribution wishes to inform its customers and the media that since yesterday, May 12, is not supplying electricity for several water supply companies, which, together, owe the company 840 million ALL in overdue payments* [6].

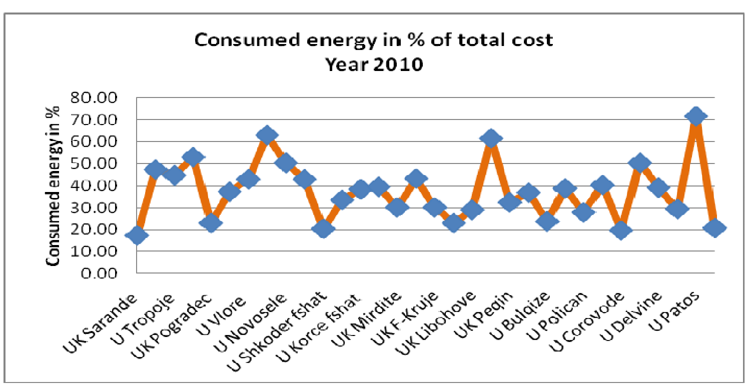
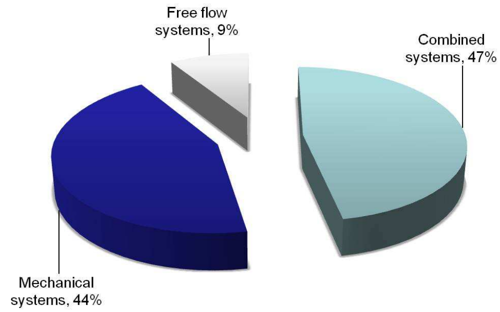


Fig.2. Consumed energy in % of total cost needed to produce water
Source: http://www.dpuk.gov.al/mat.php?idr=347&idm=85&lang=1 [7]

Cost of electricity in total spending on water supply covers a considerable weight, especially for those companies which use mechanical system. It is shown clear on fig.3 that the most of water in Albania is produced from mechanical systems. Important factor relating to this expenditure is the highest level of losses. To meet the clients' water supply due to the high level of losses, companies are forced to produce more water than needed, which directly affects the consumption of electricity.



Source: ERRU Annual Report 2010

Fig. 3. Pumping Systems in water supply sector [5].

So, the Albanian government has done subventions for water supply and sanitation companies to cover their costs instead to do investment in order to improve the performance of this important sector. For small operators tend only to improve the situation because with their incomes do not cover 50% of the costs that do.

Energy savings is very important in this sector for some reasons:

- to reduce operational costs,
- to use funds from the state budget and donors not to cover operating costs, but to invest in this crucial sector,
- better management of water resources,
- increasing the quality of services provided to consumers by increasing the duration of water supply,
- water quality and environmental protection.

One of the best ways to save electricity in this sector is the replacement of pumping systems with constant speed, already amortized, with variable speed drive (VSD). This paper will show that the using of VSD is a very good solution for flow control on pumping systems. They lead to large cost effective energy saving and very good control of electric motor speed.

3. Centrifugal pumps and the affinity laws

The pumps are always part of a pumping system. A pumping system is usually a network of pipes, tanks, valves and other system parts. Pumping systems nearly always require a variation of flow rate. While most centrifugal pumps operate at the fixed flow established by the hard-piped "free system" needs, many systems require variable flow to meet changing process demands.

The methods for controlling variable pump system output are a control valve (throttling control), bypassing, on/off and a variable speed drive.

On the constant speed system the pump speed is fixed and a control valve adds system resistance, changing the system curve and thus restricting the output of the pumping system, while consuming nearly the same amount of energy. Using variable-speed control, on the other hand instead of changing the system resistance to modulate flow, the pump speed changes. This shifts the pump's head-capacity (HQ) curve to alter the point at which it crosses the system curve. Variable-speed control changes the energy input rather than relying on a valve to strip system energy. The result is often a dramatic energy savings, fig.4.

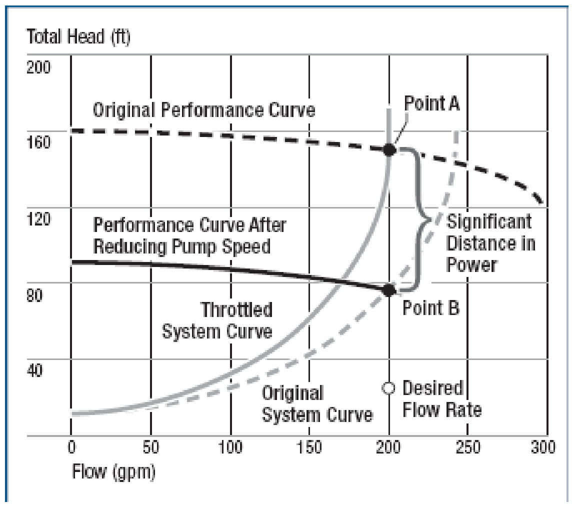


Fig. 4. Affinity laws and energy savings when use VSD compare with throttling control

While a throttled pump consumes slightly less power than it would running free, it continues to rotate at the same speed, thus maintaining high velocity in the mechanical seal and bearings, and velocity directly determines bearing and mechanical seal life.

Energy usage decreases with throttling as shown by the valve throttling curve in Fig. 4. However, speed reduction results in a more significant energy reduction. The larger the flow reduction from the free operating point, the larger the energy savings. The advantage is that centrifugal pumps performance follows the affinity laws. The affinity laws below describe the relation between the rotational speed of the pump (n), flow rate (Q), head generated (H) and power absorbed (P).

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \tag{1}$$

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 \tag{2}$$

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3 \quad (3)$$

Flow rate is directly proportional to pump speed. The differential pressure is directly proportional to the square of the pump speed. Power usage is directly proportional to the cube of the pump speed.

Based on affinity laws a centrifugal pump running at 80% speed consumes only half as much energy as a unit running at full speed. It is because the power required running a pump or fanning changes with the cube of the speed.

$$\text{Power reduction} = (1-(0.8)^3)\text{x}100 = 49\% \quad (4)$$

Energy losses in pumping processes can be categorized into adjustment losses and dimensioning losses. Energy savings can be realized, if at least one of these losses can be diminished. In many instances, adjusting the pump speed has proven to be a good solution in reducing adjustment losses in pumping. Likewise, using speed adjustment with Variable Speed Drive (VSD) can be one possible solution to decrease dimension losses in pumping systems. Because many pump systems run at less than full capacity most of the time, VSDs can produce huge savings. This will be demonstrated through the below case study.

4. Variable Speed Drive

Variable Speed Drive (VSD) means an electronic converter that continuously adapts the electrical power supplied to electric motor in order to control the mechanical power output of the motor according to the torque-speed characteristic of the load (being driven by motor), by adjusting the three-phase 50 Hz power supply to a variable frequency and voltage supplied to the motor [9].

VSD can be installed on any electric motor, but achieve the largest energy savings when applied to fan and pumping system motors [8]. The energy efficiency of almost any pump or fan system can be substantially increased by the addition of a VSD motor controller because these systems are either oversized or must respond to widely varying load conditions. In many systems excess capacity is still handled by mechanically throttling flow with dampers or valves. This is extremely inefficient because the motor continues to work hard to deliver at its full capacity. By changing the speed of the electric motors powering these pump systems, VSD allow them to follow system loads while at the same time capturing the energy efficiency benefits offered by the so-called "Affinity Laws".

VSD used in conjunction with ac machines are typically more complex and requires high initial investment. High energy cost can cause a variable-speed electric drive to be extremely attractive alternative when the application requires operation over a range of speed. Variable-speed electric drive can provide significant energy saving if they eliminate devices that are inherently inefficient at reduced speed.

Throttling valves and hydraulic coupling are example of devices that have relatively low efficiency at reduced flow rate or speed. Actual energy cost savings will vary based on mechanical characteristics and motor efficiencies.

VSDs on pumping systems offer several benefits, some of which are relatively easy to quantify, and the others are less tangible.

- ✓ Energy Saving

Electronic speed control systems with variable speed drives can be used in pumps to reduce electricity consumption by some 30% to 50%. Pumping systems are used everywhere from domestic to industrial applications. Pumping Systems subsequently account for (22 –25)% of the motor driven system electricity which roughly equates to 4% of the worlds electricity consumption.

Many existing pump systems are based on throttling arrangements: the motor is driven at full speed and then the flow of liquid or gas is regulated by valves, vanes or similar throttling mechanisms. The VSD can increase the system's efficiency by adjusting the motor speed to the correct operation point and eliminating the need for throttling. A small reduction in speed can make a big difference in energy consumption [10].

- ✓ Improved Process Control

By matching pump output flow or pressure directly to the process requirements, small variations can be corrected more rapidly by a VSD than by other control forms, which improves process performance.

- ✓ Improved System Reliability

Any reduction in speed achieved by using a VSD has major benefits in reducing pump wear, particularly in bearings and seals.

- ✓ Capital Cost Savings

On the new pumping system, the capital cost of a VSD can often be offset by eliminating control valves, bypass lines, and conventional starters.

5. Case study: Evaluation of annual operating cost saving if throttling control is replaced with variable speed drive.

To develop some energy savings guidelines, we configured a 37kW, pump/motor/drive system on pumping station, Laknas in Tirana and measured energy consumption for various static-versus-friction head scenarios. After, are compared the various scenarios to each other and to the throttled base case.

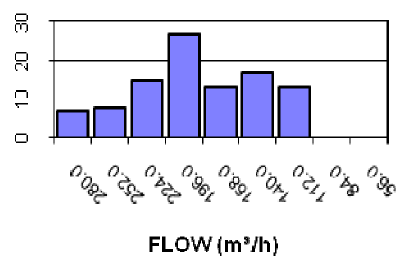
5.1. Evaluation of energy consumed on pumping system with no static head

These tests used a induction motor with four-pole, n_n =1470 rpm, P_n =37kW, U_n = 400V efficiency of 90% matched with a pump with efficiency of 80%, maximal head 54m and flow range (140-280)m^3/h. The VSD is rated at 37kW, type ACS55-01-072A-4 from ABB, efficiency 96%. Both the drive and motor are three-phase 400V. To determine saving the pump duty cycle must be considered.

So, we did measurement for one year to build the annual duty cycle for pump system with throttling control. The data are put on table 2.

Table 2. Annual duty cycle for throttling control system, 37kW in Laknas, 2009

Annual running time	**3,723h**	**Total energy**	**146,000 kWh**
7 %	260.61h	at nom. flow	
8 %	297.84h	at 90% flow	
15 %	558.45h	at 80% flow	
27 %	1005.21h	at 70% flow	
13 %	483.99 h	at 60% flow	
17 %	632.91h	at half flow	
13 %	483.99h	at 40% flow	
0 %	0 h	at 30% flow	
0 %	0 h	at 20% flow	



The calculations when the flow is controlled by VSD are made with help of PumpSave 4.4 software [11]. Figures 5 and 6 show the results when we use VSD to control flow instead of throttling control, with no static head.

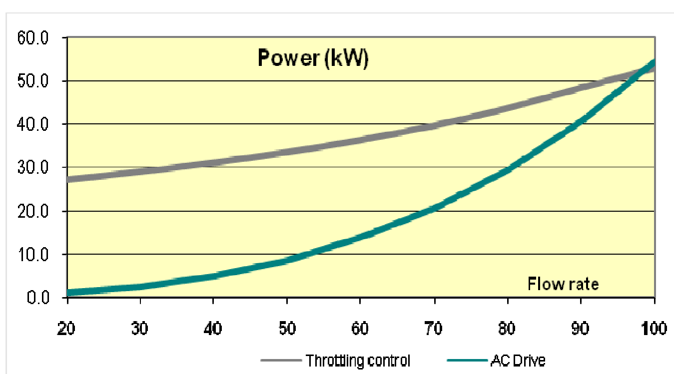


Fig. 5. Energy consumption with throttling control and VSD for different flow rate

System curves combine the effects of both static and frictional head. Static head is the height to which fluid is being pumped plus the surface pressure at the outlet less the height of the supply tank and its surface pressure. Frictional head is the frictional pressure loss in the pipe, fittings and valves.

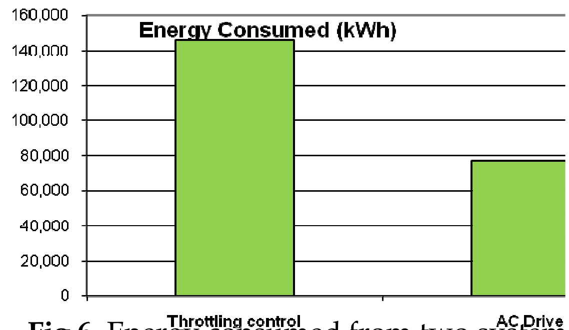


Fig.6. Energy consumed from two systems

The results on energy consumption from replacement are put on table 3.

Table 3. Results on energy consumption from replacement

Saving percentage	**48 %**	
Annual energy consumption:		
with existing control method	**146**	MWh
with improved control method	**76**	MWh
Annual energy saving	**70**	MWh
CO2 emmission/unit	0.4	kg/kWh
Annual CO2 reduction	**28**	t

The economic results from the replacement are given on table 4.

Table 4. Economic results from replacement

Annual saving	**4,908**	EUR
Energy price	0.07	EUR
VSD price&Installation	7500	EUR
Payback period	**1.5**	years
Interes rate	**5%**	
Service life	10	years
Net present value (LCC)	**30,399**	EUR

5.2. Evaluation of energy consumed from pumping system with different static heads

In systems exhibiting only frictional head loss, flow rate can be reduced by slowing the pump. The power savings mount as the pump slows. In systems with high static head, the operational flow point is continuously moving toward the pump minimum flow as speed drops. A minimum operating speed is required to overcome the static pressure difference, Therefore, the energy savings are limited.

The greatest energy savings occur in low-static-head applications that use a VSD in place of a throttling valve.

However, using a VSD to operate at reduced flow rate against high static head still produces savings over throttling, though the result is not as dramatic. The data on on table 5 show clear this conclusion.

Table 5. Energy consumption for different static heads

Static Head	m	**0**	**10**	**30**	**40**
Saving percentage	%	48 %	39.2%	22.7%	14.9%
Annual energy consumption:					
with existing control method	MWh	146	146	146	146
with improved control method	MWh	76	83	113	124
Annual energy saving	MWh	70	57	33	22
CO2 emmission/unit	kg/kWh	0.4	04		
Annual CO2 reduction	t	28	23	13	9

5.3.Evaluation of energy consumed from pumping system different annual running time

Also, we have done calculations when VSD application works with different annual running time, no static head. The economic results about energy saving and payback time are given in following table:

Table 6. Energy saving and payback time

Annual Working hours	hour	**3723**	**2000**	**5000**
Annual saving	EUR	**4,908**	**2,637**	**6,592**
Energy price	EUR	0.07	0.07	0.07
VSD price&Installation	EUR	7500	7500	7500
Payback period	years	**1.5**	**2.8**	**1.1**
Interes rate		**5%**	**5%**	**5%**
Service life	years	10	10	10
Net present value (LCC)	EUR	**30,399**	**12,860**	**43,399**

The taken results show that the economic results are better when VSD application is running for long time.

Conclusions

The aim of this paper is to show through practical measurements and calculations the important electricity savings by using variable speed control on pump systems, great impact on finance situation of water sector in Albania and environment improvement. Using variable speed drives (VSDs) in adjusting the pump speed has proven to be an energy efficient way to decrease the adjustment losses in pumping processes.

The using of VSD is a very good solution for non fixed speed systems. They lead to large cost effective energy saving and very good control of electric motor speed.

Expect of energy saving VSD has important technical advantages as: reduced wear and tear on the machinery due to soft-starting/stopping and lower speed operation.

Because systems with only friction head provides the most likely energy-saving scenario and those with greater static head provide the least, making a decision on VSD or throttling appears simple. However, most applications fall somewhere in the middle, making the economics less clear.

Using variable speed drive in pump systems brings important electricity savings from 20%-50% when pump system works with changeable duty cycle, annual working hours are more than 2,000 h/year, electric power of motor is over 25kW, high load coefficient, high pump efficiency, using efficient motor instead of standard one etc. Energy savings are very important for the actual situation of water sector in Albania with impacts on financial management, better management of water, increasing of services quality, environment protection.

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