STAND-ALONE PV PUMPING SYSTEM ADJUSTMENT BY VALVE-THROTTLING CONTROL

REGULATION D'UN SYSTEME DE POMPAGE PHOTOVOLTAÏQUE AUTONOME PAR VANNE DE LAMINAGE

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RESUME

Les systèmes de pompage photovoltaïques autonome de l'eau est l'un des meilleurs choix, en particulier dans les régions isolées. Dans la plupart des cas, l'énergie photovoltaïque est utilisée directement à partir des panneaux photovoltaïques sans conversion ou stockage. La particularité des pompes installées au fils du soleil, est que leurs caractéristiques (débit, HMT, puissance, vitesse de rotation) dépendent de l'ensoleillement qui varie au cours de la journée et au cours des saisons de l'année. Les pompes installées dans ce système doivent être ajustées pour qu'elles travaillent dans le meilleur rendement et avec le débit requis.

La régulation par vanne de laminage est une des méthodes couramment utilisés pour ajuster et régler le débit dans les systèmes de pompage. Cette méthode a un impact direct sur les performances de la pompe (de la consommation d'énergie, la quantité d'eau délivrée, rendement ...) et sur son point de fonctionnement.

Dans cet article, nous montrons un essai de laboratoire des pompes solaires centrifuges, où leurs caractéristiques ont été déterminées par régulation vanne de laminage. En comparant les résultats obtenus avec ceux donnés par le constructeur, nous observons une perte considérable de l'HMT et de l'énergie qui peut être traitée dans la présente étude.

MOTS CLES: Pompe au fil du soleil, photovoltaïque, régulation par laminage, vitesse de rotation.

ABSTRACT

Stand-alone photovoltaic water pumping system is one of the best choices, especially in remote areas. In the most cases, the photovoltaic energy is used directly from photovoltaic panels without conversion or battery storage. The particularity of pumps installed along the sun, that their characteristics (flow rate, head, power, rotation speed) depends on solar irradiations which varies over the days and seasons of the year. Pumps installed in this system have to be controlled to keep them working in the best efficiency and with the required flow rate.

Valve-throttling control is one of control methods commonly used to adjust and to control the flow rate in pumping systems. This method has a direct impact on pump performances (power consumption, amount of water delivered, efficiency...) and its operating point.

In this paper, we show a laboratory test of the centrifugal solar pumps, where their characteristics were determined by the valve-throttling control. Comparing the results obtained with those given by the manufacturer, we note a considerable loss in the head and energy which can be treated in this study.

KEYWORDS: PV pumping system, stand-alone, pump control, throttling, rotation speed.

1 INTRODUCTION

Pumping water in arid areas isolated from the electric grid represents a challenge, the best choice in this case is the stand-alone photovoltaic system to feed the water pumping system for a suitable application.

Usually in the stand-alone water pumping system, the photovoltaic energy is used directly from photovoltaic panels without conversion or battery storage. The only way to store energy is in the form of hydro potential for later use such crop irrigation.The particularity of solar pumps installed on this system, that their characteristics (flow rate, head, power, rotation speed) depends on solar irradiations which varies over the days and seasons of the year. Pumps installed in this system need to be controlled to keep them working in the best efficiency and with the required flow rate.

Many control methods exist in literature to adjust and to control the flow rate in pumping systems at constant speed or by variation of speed.

At constant speed, the flow rate control can be carried out in many ways such as [1]:

- Throttling control valve
- Bypass control
- Change in impeller diameter
- Impeller blade adjustment
- Adjustable guide vanes

In this study, we are interested in valve-throttling control which is the cheapest, the most economic and commonly used in pumps with low and medium power. A few studies were focused on the valve-throttling control in direct-coupled photovoltaic water pumping systems where the rotation speed of the pumps is variable and depend on solar irradiation, we mention:

H. AMMAR, MT. Bouziane, Y Bakelli [2], studied the influence of flow variation by throttling on the performance of a solar pump at a fixed total monomeric head. He stated that the throttling way (gradually or abruptly) has a direct consequences on the decreases of the pump performances.

In similar work, H. AMMAR et al [3], followed the operating point of a solar pump installed along the sun at fixed and variable total monomeric head. He stated that the throttling control causes a fluctuation of the operating point.

In another work, H. AMMAR, MT. Bouziane [4], studied the flow rate regulation and performance of a pump installed along the sun by throttling in clear and cloudy day, he concludes that the climate has an impact on the flow control for solar pumps installed along the sun.

In this paper, we show a laboratory test of a centrifugal solar pump, where its characteristics were determined by the valve-throttling control. The total dynamic head of the pump is not fixed, it is variable for each input power range and for each value of rotation speed of the pump.

This manipulation allows us to determinate the head-flow characteristic curves and photovoltaic impute power-flow characteristic curves of the pump for the whole day and for each range of power and rotation speed.

In the following sections, the pumping test bench is described in more details, the results are presented and compared with those given by the manufacturer. The comparison shows a considerable loss in the total head and energy which is interpreted and treated for the proposed method.

2 DESCRIPTION OF THE PUMPING TEST BENCH

The photovoltaic pumping system is tested on a test bench at URAER (Applied Research Unit for Renewable Energies Ghardaïa), it forms a stainless steel closed circuit as it's illustrated in the figure 1.

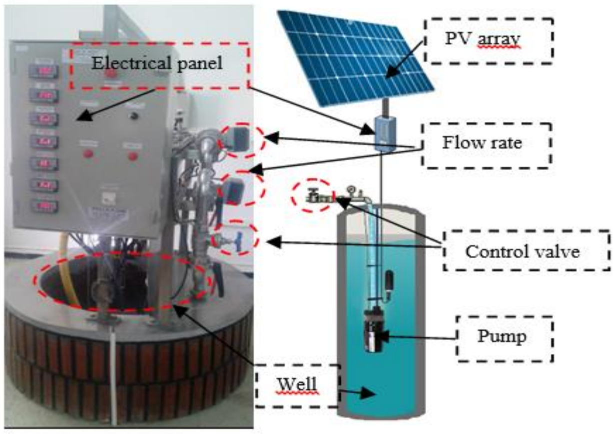

Figure 01: PV pumping test facility

The main elements of this system are as follows:

2.1 Solar modules

The photovoltaic modules used in the experimental procedures are type monocrystalline silicon made by Isofoton, each comprising 72 cells and a peak power of 110W. The number and configuration of the solar panels depend on the pump test.

2.2 Tank

Tank in stainless as an artificial well with depth of 02 meters.

2.3 Measuring equipment and devices

a. Two flow meters are installed to measure the flow rate and daily amount of water.

b. Two pressure transducers for high and low pressure to measure the pressure and determinate the total head of the pump.

c. Control valve (throttling valve control).

d. Solar sensor which is a silicon sensor was used for global irradiance measurements.

e. Electrical panel for control and display, it include voltage and current sensors.

2.4 Acquisition

A data logger type Agilent 34970A was used to records data on PC for analysis.

2.5 Pump

The centrifugal pump used in this test is designed and made by Grundfos and is the SQF 5A-6 type:

The Technical specifications of the use pumps are summarized in the following table:

Table 01: Technical specifications of the pump

GRUNDFOS SQF 5A-6		
Pump	Model number Pump design Materials Maximum head Weight Dimensions	SQF 5A-6 Centrifugal with radial impellers, 6 stages stainless steel dry running protection 30 m 10.3 875 x 101
Motor	Motor type Nominal voltage Nominal power Maximum amperage	Permanent magnet, stainless steel 130 V 900 W 7 A

3 METHODOLOGY

Usually, valve-throttling control is used in pumping systems at constant speed, where pumps are tested in the laboratory to determine the daily amount of water delivered by the pump as a function of the daily irradiations and of the total head. These tests, maintains the total head along a pumping shift. For each head we must do the same test which takes a longer time to determine the performance of the subsystem pump-motor. We propose another type of manipulation (figure 2), we use the valve-throttling control in pumping systems, but at variable speed which depend on solar irradiations, in this case we use the control valve installed at the outlet of the discharge line, to gradually change the total head of the pump as a function of the daily irradiations and for the whole day.

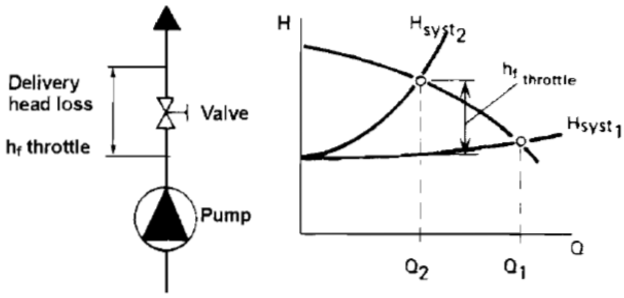

Figure 02: Throttling by control valve, schematic and curves [5]

Theoretically, the valve- throttling control of water pumping system along the sun , became a combination between pumping system with valve-throttling control at constant speed (Hsyst, figure 3) in closed loop and pumping system with variable rotation speed (N, figure 3) which in turn depends on solar irradiations.

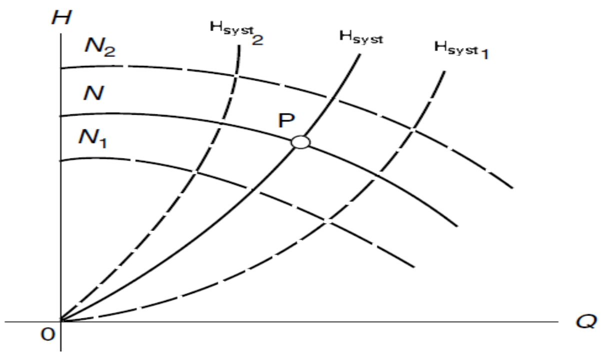

Figure 03: Throttling control effects on characteristic curves of a solar pump

4 RESULTS

The manufacturer's curves for the select pump were obtained from PVsyst (v5.55) software through pumps database.

The rotation speed of the pump can be obtained from the power using the affinity laws.

4.1 Head-flow characteristic

Through these tests we obtain head-flow characteristic curves of the pump for each power and rotation speed by classification thereof for the whole day.

The figures below summarizes the head-flow characteristic curves of the select pump and their comparison with manufacturer's curves for each power range:

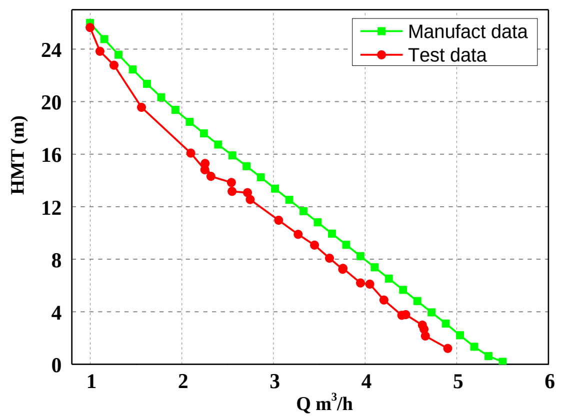

Figure 04: H vs. Q characteristics at 310 W array power

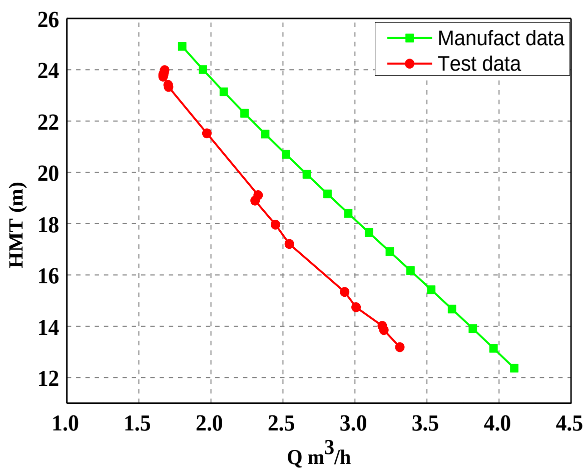

Figure 05: H vs. Q characteristics at 390 W array power

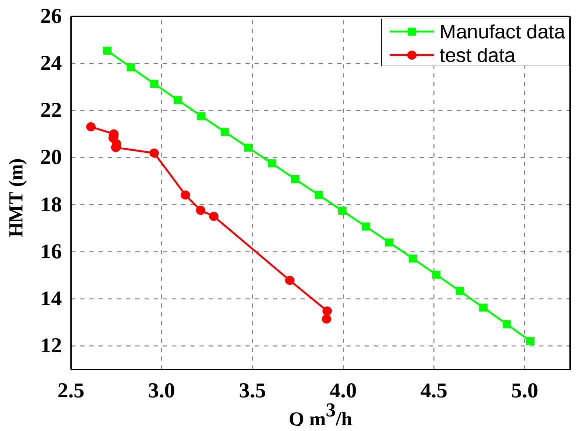

Figure 06: H vs. Q characteristics at 490 W array power

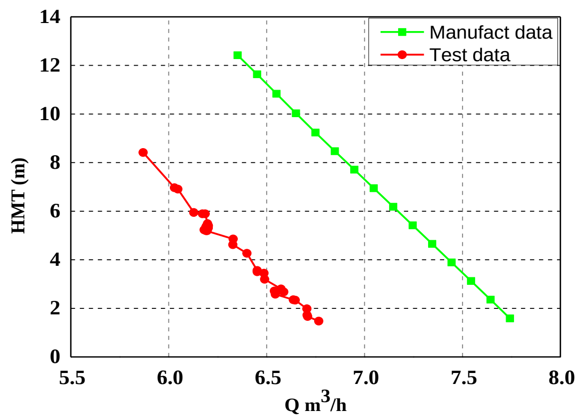

Figure 07: H vs. Q characteristics at 700 W array power

4.2 Power- flow characteristic

By the same procedure, the photovoltaic input power- flow characteristic curves of the pump for each total head is obtained by classification thereof for the whole day.

The figures below summarizes the power -flow characteristic curves of the select pump and their comparison with manufacturer's curves for each total head:

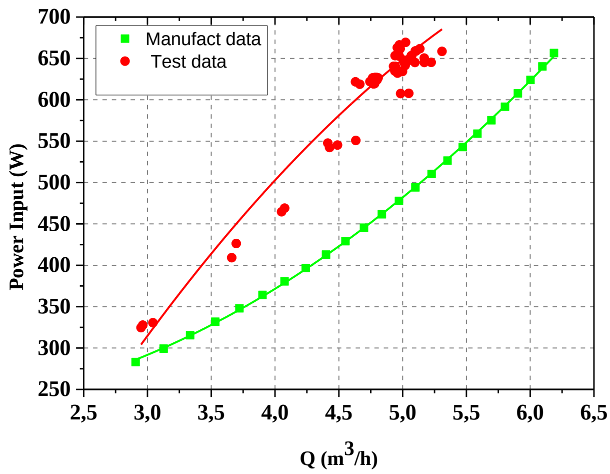

Figure 08: P vs Q of the pump for a total head =12 m

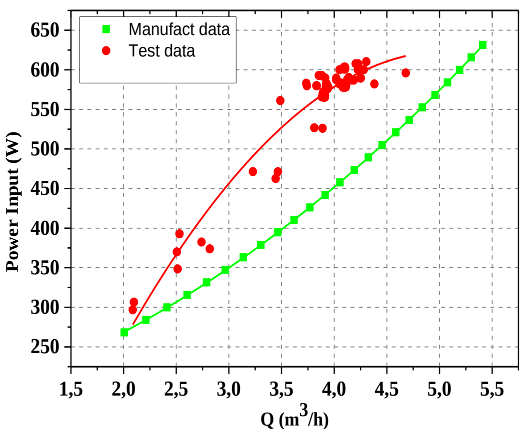

Figure 09: P vs Q of the pump for a total head =16 m

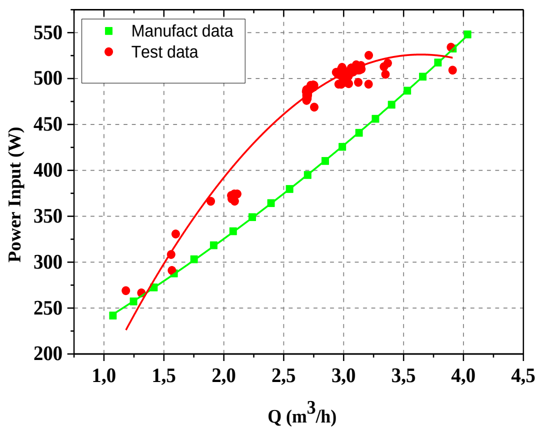

Figure 10: P vs Q of the pump for a total head =20 m

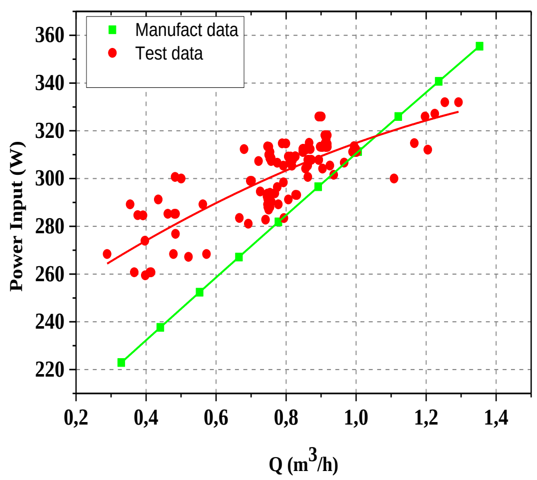

Figure 11: P vs Q of the pump for a total head =26 m

5 RESULTS INTERPRETATION

5.1 Head-flow characteristic

The System head usually consists of a combination of static and frictional components, although the relative value of these two components varies considerably from one system to another. In our case in a closed loop system is composed entirely of friction head [6].

The figures 4, 5, 6 and 7 show the head-flow characteristic come from test data and from manufacturer data of the pump for each power range (310, 390, 490, and 700 W),the comparison between them shows a modification in the system-curve characteristics, a gap in the total head and increasing in the slop of the system curves. This gap seems clearer, especially for high range of power and discharge (figure 6 and 7).

The gap in the total head can be explained by an increase in friction head loss in the valve control and the pressure loss in the discharge pipe, these losses are due to the increase of power and rotation speed of the pump, because the friction loss in a piping system varies as the square of the liquid's velocity.

As a result the flow rate increase in the discharge pipe and the throttle frequency increases as well to reach the desired flow.

5.2 Power- flow characteristic

The figures 8, 9, 10 and 10 show the power-flow characteristic come from test data and from manufacturer data of the pump for each value of total head (12, 16, 20, and 26 m), the comparison between them shows a loss in power and waste of energy.

The figure below (figure 12) shows Comparison between several regulation methods.

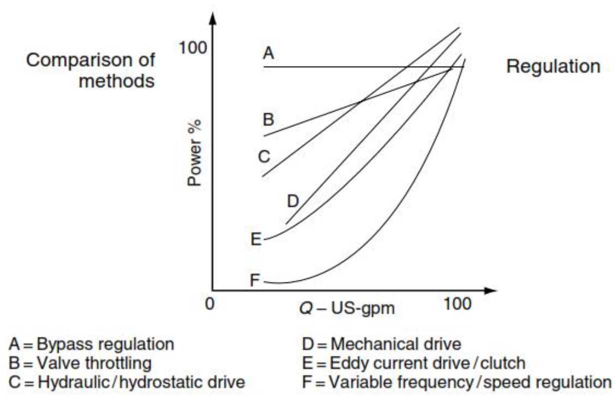

Figure 12: Comparison of methods of regulation [1]

The figure below (figure13) shows Power-flow characteristic of a pump, where each curve represents a type of control as follows:

- Curve AA: constant speed with discharge throttling.
- Curve BB: synchronous motor with variable-speed hydraulic coupling on each pump.

- Curve CC: variable-speed wound-rotor induction motor.
- Curve DD: dc motor with rectifier and shunt field control.
- Curve EE: synchronous motor with variable-speed constant-efficiency mechanical speed reducer.

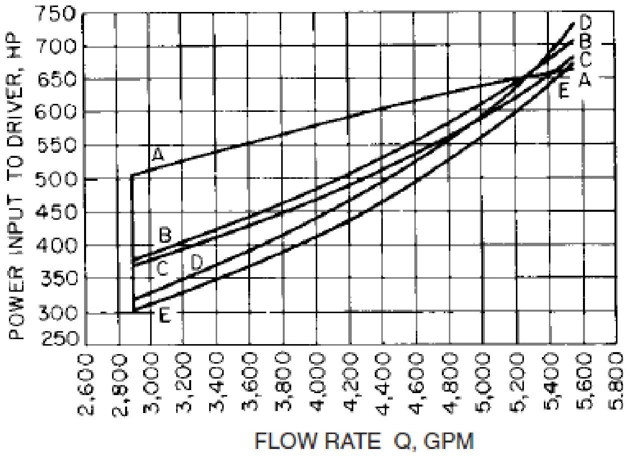

Figure 13: Power requirements of a pumps operated at constant head and variable flow rate. [7]

According to the figures 12 and 13 and their comparison with the previous figures (8, 9 10 and 11) we can note that the power-flow characteristic of direct-coupled solar pump with valve-throttling control does not follow any curves in Figure 12 or 13, but it is a combination between several curves (curve A and D figure 12), (curve AA and curve DD figure 13).

The trend of power-flow characteristic curve of the pump depend on total head to which the pump operates. For total head = 26m, the flow characteristic curve is similar to the curve B (figure 12) or curve AA (figure 13) which can be explained by the fact that BEP of the pump is correspond to total head =26 m [3].

The waste of energy in a simple valve-throttling control at a constant speed such as curve B is explained in figure below (figure 14) [8].

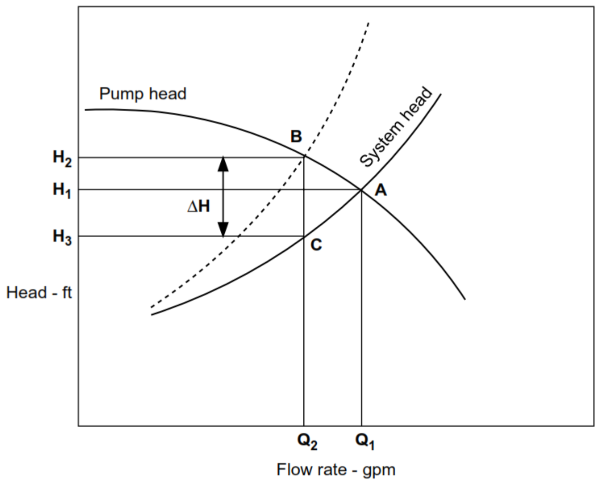

Figure 14: Illustration of power wasted by throttling [8]

The throttled head ΔH, and thus the throttled pressure, represents a wasted pump head and correspondingly wasted energy. [8]

The figure 15 shows the effect on performance of wear in seals, clearances and pump blades, which the first graph of this figure is similar to the figures 5, 6, and 7, or the second graph of this figure is similar too to the figure 11.

According to the figure 15 and its comparison with the previous figures, we see the effect of valve-throttling control on the decreasing of the performances of direct-coupled solar pump by wear in seals, in clearances and in the pump blades and this is due to the reduction in the available net positive suction head, leading to cavitation.

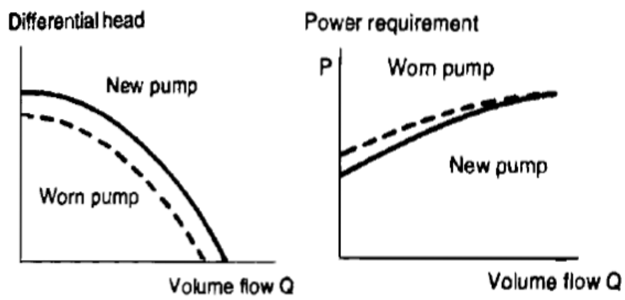

Figure 15: The effect on performance of wear in seals, clearances and pump blades [5]

Through this method of control (Valve-throttling control), we notice that the used method is an inefficient method for the installed system. The inefficiency is due to several reasons we mention:

- Increase in friction head losses.
- Modification in the system-curve characteristics and the operating point moves on the Head-flow curve.

- Moving the operating point of the pump to the left or right of BEP reduces the pump efficiency.
- The waste of energy and head by valve-throttling control.
- Reduction in the available net positive suction head.
- Decreasing of the performances of the pump by wear in seals, in clearances and in the pump blades and this is due to cavitation.

6 CONCLUSION

In this study, we have presented a performance test in the laboratory of a solar pump installed along the sun, where the characteristic curves have been determined by the valve-throttling control. This type of control method has a direct impact on losses on head, energy, and efficiency of the pump.

The study of the trend of system curves can be perfected by the studies of system curves apart for each power range and for each value of the total head. This study can be completed by other reflections such as the study of the trend of the efficiency for each power range and for each value of the total head.

In conclusion, the use of the valve-throttling control should be limited to small variations in the pump flow rate and when the regulation required is temporary in order to avoid considerable power loss and a significant reduction in system efficiency.

Using a variable speed control for flow rate control represents a better alternative of the pump helps because it maintain high pump efficiency and to reduce energy consumption.

When permanent regulation is desired other regulation techniques may be used like modifications to the impeller which can eliminate the unnecessary throttling in the system. The choice of throttling is dependent upon the size of the pump, specific speed, the cost of energy and how often throttling will be used and for how long.

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