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# ENERGY SAVING FOR A PUMPING STATION SERVING AN ON-DEMAND IRRIGATION SYSTEM: A STUDY CASE

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**SUMMARY** - In this study, a new approach combining new technologies and simulation tools to identify potential energy savings was set up and tested in a pilot on-demand irrigation system. The use of variable speed pumping station is proposed and compared with a constant speed one.

The characteristic curves of the pumps were computed under field conditions. Demand curves of the irrigation network were determined by means of Indexed Characteristic Curve model. Variable Speed Drive (VSD) was used to match pump characteristic curves and irrigation system demand curve. Water balance model was applied for simulating the upstream discharge. According to the obtained discharge hydrograph, total operation time was identified. Since power requirement and discharge frequencies were known, energy consumption was calculated.

As a result, compared to the constant speed pump operation, total energy saving achieved was equal to 32.9%.

**Key words:** Energy saving, pumping cost, on-demand irrigation system, variable speed drive.

**RESUME** - Ce travail a établi une nouvelle approche qui combine de nouvelles technologies et des outils de simulation pour identifier et tester des économies potentielles d'énergie dans un système pilote à la demande.

*Les courbes caractéristiques des pompes ont été calculées dans les conditions de plein champ. Les courbes de la demande du réseau d'irrigation ont été déterminées par le modèle des Courbes Caractéristiques indexées. Le variateur de vitesse (Variable Speed Drive-VSD) a été simulé pour joindre les courbes caractéristiques des pompes à la courbe de la demande du système d'irrigation. Un modèle de bilan hydrique été utilisé pour simuler le débit en amont. En se référant à l'hydrographe des débits obtenu, toutes les opérations de temps étaient identifiées. Puisque la puissance demandée et la fréquence des débits étaient connus, l'énergie consommée été calculée*

*Par rapport au fonctionnement avec pompe à vitesse constante, une économie totale d'énergie de 32.9% à été réalisée.*

**Mots clés :** Economie d'énergie, coût de pompage, système d'irrigation à la demande, variateur de vitesse.

## INTRODUCTION

A pumping station is often designed to meet the maximum design discharge, which may occur just for a limited time. In on-demand irrigation systems, there is a variation in flow and pressure as a result of seasonal changes in crop water requirements and farmer's behavior (e.g., a farmer may decide independently when starting to irrigate). The amount of consumed energy depends on the system flow rate, operating pressure and time of operation. Savings can be realized by reducing these variables. Consequently, either the system characteristic curve or the pump characteristic curve should be changed to get a different operating point.

Some techniques can be used to reduce energy consumption: decreasing the volume of water to be pumped (e.g., adjusting pressure zone boundaries), lowering the pressure head (e.g., optimizing tank water level range), or reducing the costs of energy (e.g., avoiding peak hour pumping and making effective use of storage tanks such as filling them during off-peak periods and draining them during peak periods), and increasing the pump efficiency (e.g., ensuring that pumps are operating near their best efficiency point). However, all these techniques do not necessarily match the pump characteristic curve to the system characteristic curve.

The largest decrease in energy costs, without sacrificing crop yields, is realized by lowering operating pressures without decreasing efficiency and performance. In this perspective, this paper is addressed to find a criteria able to supply the minimum required pressure according to the variability of irrigation water demand in an on-demand irrigation system. This methodology will allow to match pump and irrigation characteristic curves along all the duration of irrigation season in order to save energy consumption saving respect to a classical approach. A flowchart of the variable speed approach is shown in Fig. 1.

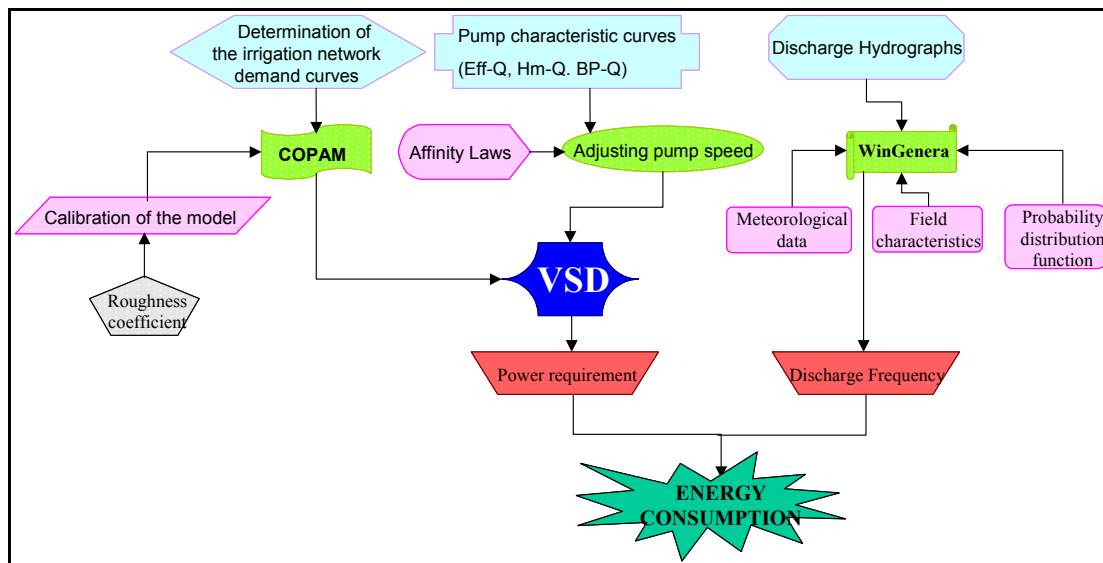


Fig. 1. Flowchart of the variable speed approach.

## MATERIALS METHODS

A methodology for energy saving was set up and tested in a pilot on-demand irrigation system on the experimental field in the CIHEAM-IAMB Institute. A pilot irrigation system is supplied by a pumping station serving an irrigable area of 36.9 ha equipped with 8 hydrants of 5 l/s nominal discharge, requiring a minimum pressure head of 30 m. (Fig. 2). The irrigation network was designed for 'on-demand' operation. The pumping station is equipped with 2 vertical centrifugal electrical pumps. Each pump can be operated either with variable speed or fixed speed. The main water supply to the system is a reservoir having the capacity of 215 m<sup>3</sup>.

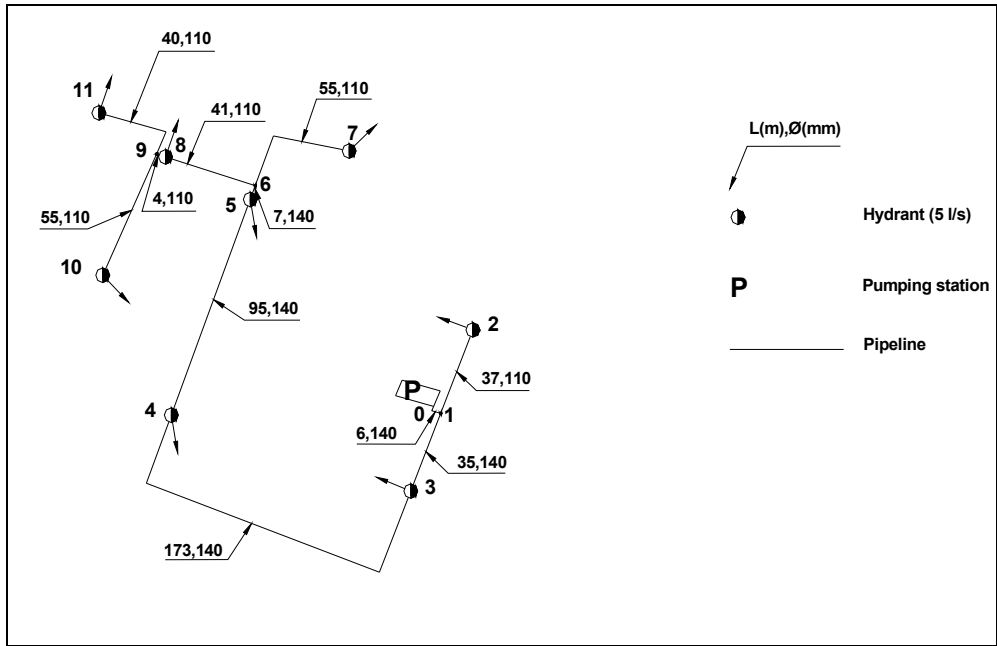


Fig. 2. Layout of the irrigation network.

### Pump characteristic curves

Pump characteristic curves (Hm-Q, BP-Q, Eff-Q) were computed under field conditions. Hm-Q curve was determined in case of a single pump and two pumps installed in parallel. The experimental values obtained from tests were fitted by analytical curves (Fig. 3). Moreover, the curves were adjusted to various speeds of the pump using Affinity Laws, which were also verified under field conditions. In Fig. 3, the marked points and line represent the experimental points and the effect respectively.

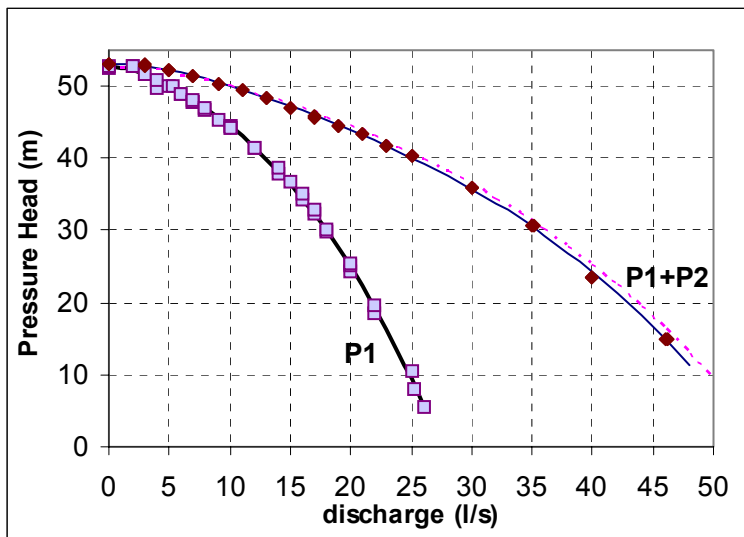


Fig. 3. Observed and expected Hm-Q curves for two pumps in parallel.

Pump efficiency hill curves were defined for different pump speeds (Fig. 4) and the following formulas were used:

$$\eta_p = \frac{WP}{P_r} \quad (1)$$

Where;

$$WP = \frac{H_m \times Q}{K} \quad (2)$$

WP= Water power output [kW]

K = Conversion constant.

H= Total dynamic pressure head, [m]

Q = Discharge, [ $\text{l s}^{-1}$ ]

$\eta_p$  = pump efficiency.

$$P_r = \frac{1.73 \times V \times I \times \cos \varphi \times \eta_m}{1000} \quad (3)$$

where;

$P_r$  = Motor rated power, [kW]

V = Current voltage, [V]

I= Absorbed amperes, [A]

$\eta_m$  = Motor efficiency

$\cos \varphi$  = Power factor.

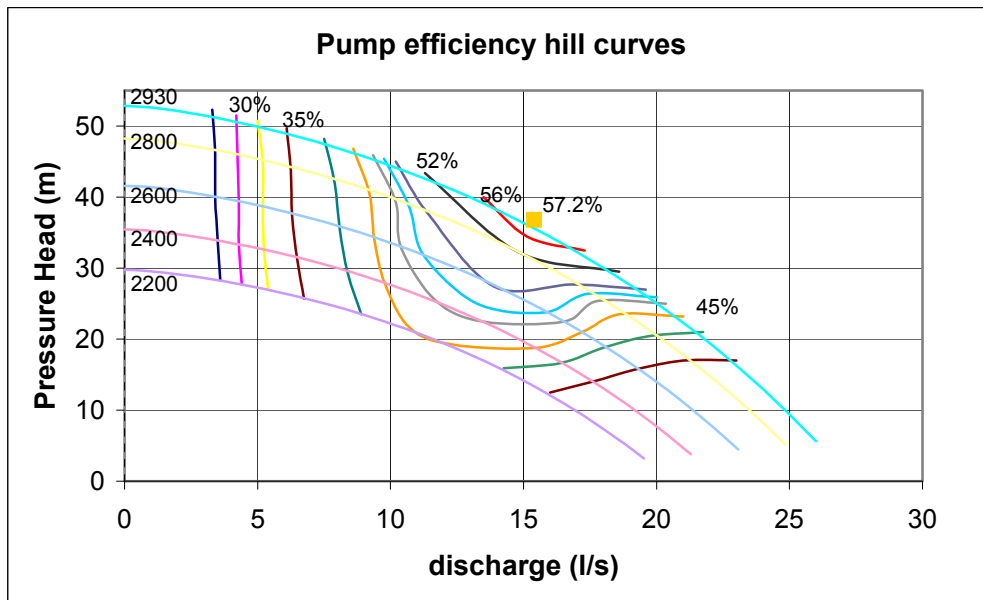


Fig. 4. Pump P8B/3/202B iso-efficiency hill curves.

#### Determination of the demand curves

Performance analysis of a pumping station requires the preliminary analysis of the network characteristic curves that limit the possible operating points of the pumping station. In on-demand pressurized irrigation systems, for the same upstream discharge, pressure requirement may vary

according to the number of hydrants that are open simultaneously and their positions on the network. It means that there is not only one "demand curve" in the network, but a range of pressure values for each required discharge. Demand curves of the irrigation network were determined with the Indexed Characteristic Curve Model by the use of COPAM software (Lamaddalena and Sagardoy, 2000).

Under the hypothesis that any operating hydrant may deliver the nominal discharge,  $d$  [ $l\ s^{-1}$ ], let us redefine "configuration" ( $r$ ) as a group of operating hydrants ( $j$ ) corresponding to a fixed value of the nominal discharge,  $Q$  [ $l\ s^{-1}$ ], at the upstream end of the network. A configuration is satisfied when, for all the operating hydrants of the configuration, the following relationship is respected:

$$(H_j)_r \geq H_{\min} \quad (4)$$

where  $(H_j)_r$  [m] represents the pressure head of the hydrant  $j$  within the configuration  $r$ , and  $H_{\min}$  [m] represents the minimum required pressure head for appropriate operation of the on-farm system.

For each configuration, the satisfaction of the condition (4) depends on the plano-altimetric location of the operating hydrants. In general, the network is able to satisfy only a percentage of the possible configurations. For any value of the discharge,  $Q$ , flowing in the upstream section of the network, within zero and  $Q_{\max}$  (discharge corresponding to the total number of hydrants in operation), different values of the piezometric elevation,  $Z_r$  [m.a.s.l.], satisfy the relationship (4), each one corresponding to a different hydrant configuration. Therefore, if for all the possible configurations  $r$ , the couples  $(Q_r, Z_r)$  referred to discharges ranging between 0 and  $Q_{\max}$  are calculated, a cloud of points (Fig. 5) is observed within an envelope in a plane  $(Q, Z)$ . Each point  $P_u(Q_r, Z_r)$  of the upper envelope curve gives a piezometric elevation  $Z_r$ , at the upstream end of the network, which fully satisfies condition (4) for every discharge  $Q_r$ . Each point  $P_l(Q_r, Z_r)$  of the lower envelope curve gives a piezometric elevation  $Z_r$  for which it is not possible to satisfy the condition (4). In other words, the upper envelope corresponds to 100% of satisfied configurations (relationship 4), while the lower envelope concerns a situation where any configuration is not satisfied (Bethery, 1990; Lamaddalena, 1997; Lamaddalena and Sagardoy, 2000) (Fig. 5).

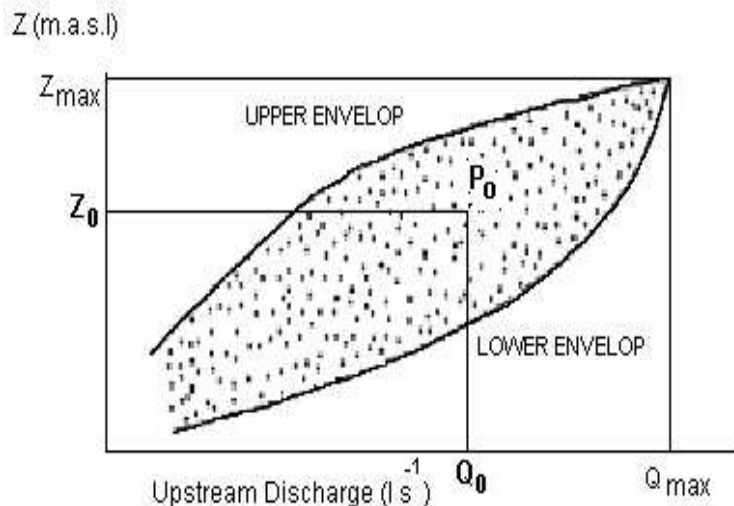


Fig. 5. Representative points of the hydraulic performance of a network (Lamaddalena, 1997)

It is then possible to obtain other curves, between these two envelopes (i.e. indexed characteristic curves) that represent a percentage of satisfied configurations.

The complete investigation of all the possible configurations leads to a large number of cases, equal to

$$C_R^K = \frac{R!}{K!(R-K)!} \quad (5)$$

where  $C_R^K$  represents the number of the possible configurations when the discharge  $Q_r$  is delivered, corresponding to  $K$  hydrants simultaneously operating, where  $R$  is the total number of hydrants in the network.

One can establish a given discrete number of discharges where each of them correspond to a number,  $K$ , of simultaneously open hydrants:

$$K = Q_r / d^1 \quad (6)$$

The number  $C$  of configurations to be investigated for each discharge should be close to the total number of hydrants ( $R$ ) (Lamaddalena, 1997). Therefore, once  $C$  is known, a generator of random numbers, having uniform probability distribution, is used. Thus, the  $K$  hydrants for each configuration are drawn in the range between 1 and  $R$ .

### Demand hydrographs

A demand hydrograph represents the discharge withdrawal at the upstream end of the irrigation network versus the time (Fig. 6).

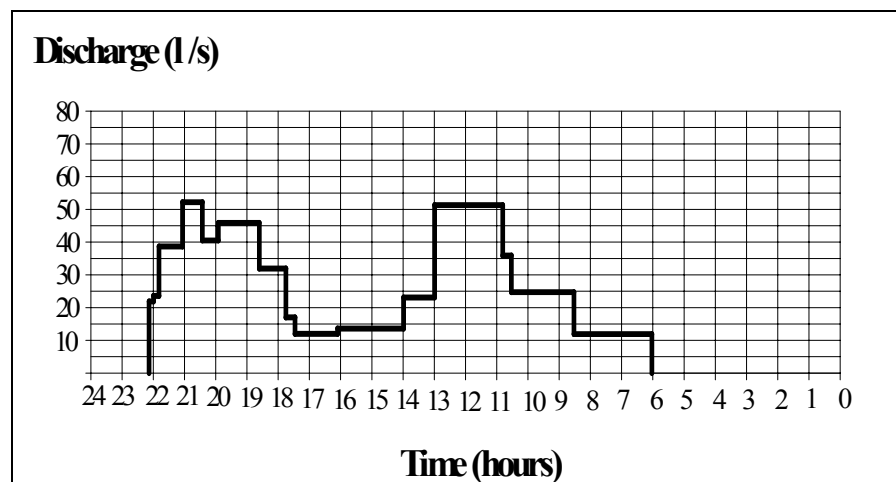


Fig. 6. Example of a typical demand hydrograph at the upstream end of an on-demand irrigation network.

As the pilot irrigation system is not available, the demand hydrograph was unknown. Therefore, the water requirement for each field has been determined by maintaining soil water balance according to field characteristics like cropping pattern, soil type, weather conditions, seed date, on-farm irrigation methods, and farmer behavior. A simulation model called WINGENERA (Khadra and Lamaddalena, 2005) was used to determine water demands at the hydrant level and to aggregate them up to head of the network. Data (daily weather and rainfall, field characteristics) collected during the irrigation season 2004-2005 have been used for the simulation. Finally, discharge frequencies for each discharge class were identified.

<sup>1</sup> This assumption implies that all the hydrants have the same nominal discharge,  $d$ .

The daily water balance for each field downstream each hydrant could be expressed by the following equation:

$$I_n = ET_c - (P_e + GW + W_e) \quad (7)$$

$I_n$  = net irrigation requirement ( $\text{mm d}^{-1}$ )  
 $ET_c$  = actual crop evapotranspiration ( $\text{mm d}^{-1}$ )  
 $P_e$  = effective rainfall ( $\text{mm d}^{-1}$ )  
 $GW$  = ground water contribution ( $\text{mm d}^{-1}$ )  
 $W_e$  = soil moisture contribution ( $\text{mm d}^{-1}$ )

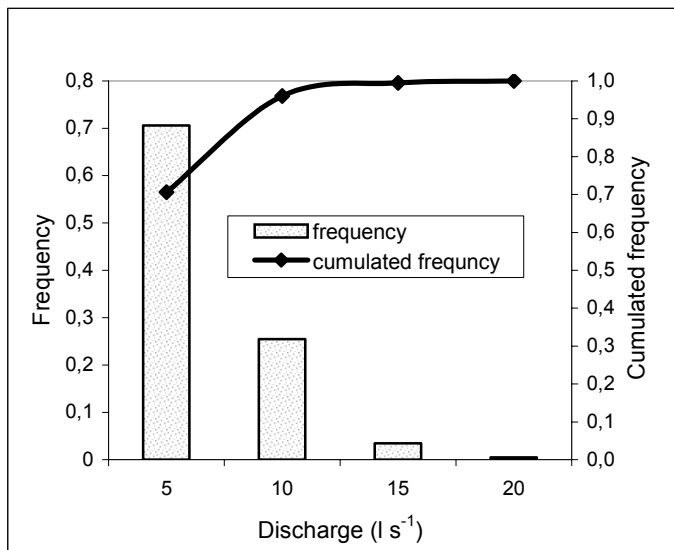


Fig. 7. Histogram of frequencies for the discharges generated at the upstream of the irrigation network.

Fig. 7 shows the frequency histogram of discharges. It shows the withdrawals variability during the irrigation season. Cumulative frequency explains the total number of hours that irrigation pumps are operating.  $5 \text{ l s}^{-1}$  discharge has the highest probability of occurrence with 70.61% while  $20 \text{ l s}^{-1}$  has 0.49% probability of occurrence. During this calculation, zero discharge was not taken into account.

### Energy Consumption

The energy consumption depends on the power demand and operating time. By knowledge of abovementioned factors, it is possible to estimate the energy consumption of the pumping station.

In order to compare energy consumption between variable speed and constant speed pump operation, power requirement for each discharge class were calculated. Since all the hydrants have nominal discharge of  $5 \text{ l s}^{-1}$ , the interval value of  $5 \text{ l s}^{-1}$  was considered. Thus, the calculations were done for 5, 10, 15,  $20 \text{ l s}^{-1}$ .

The maximum speed of the pump was considered 2930 rpm at 50 Hz according the pump characteristics. The value was confirmed by tests using a stroboscope. Motor efficiency was considered as 90 % according to motor company information.



For discharges greater than  $16 \text{ l s}^{-1}$ , for constant speed operation, second pump starts to operate together with the first pump (Fig. 9). In the case of discharges lower than  $16 \text{ l s}^{-1}$ , the speed of the second pump is put “zero”.

The same procedure described above was applied to variable speed operation. The pressure head requirement has been determined for each discharge class and indexed characteristic curves were used for this practice. 90% indexed characteristic curve was considered. Pump efficiency values,  $\eta_p$ , are taken from pump’s efficiency hill curves. Finally, pump and motor power were calculated.

Generated discharge hydrographs were used to calculate the withdrawal discharge and the corresponding durations. Consequently, formulas below were used to calculate total energy consumption for irrigation.

$$P_a = \frac{P_r}{\eta_m} = \frac{BP}{\eta_m} = \frac{H_m \times Q}{102 \times \eta_p \times \eta_m} \quad (8)$$

$P_a$  = Absorbed power, [kW]

$BP$  = Brake power, [kW]

The energy consumption is given by:

$$E = P_a \times T \quad (9)$$

where;

$E$  =Energy, [kWh]

$T$  = Operation time, [h]

## RESULTS AND DISCUSSION

### Use of indexed characteristic curve model

In Fig. 8, the indexed characteristic curves applied to the irrigation network are represented. 70 random configurations were done to draw the curves corresponding to upstream discharges of  $1 \text{ l s}^{-1}$  to  $40 \text{ l s}^{-1}$ . Pumping station was designed for a maximum discharge of  $20 \text{ l s}^{-1}$  with an upstream piezometric elevation of 120.2 m.a.s.l.

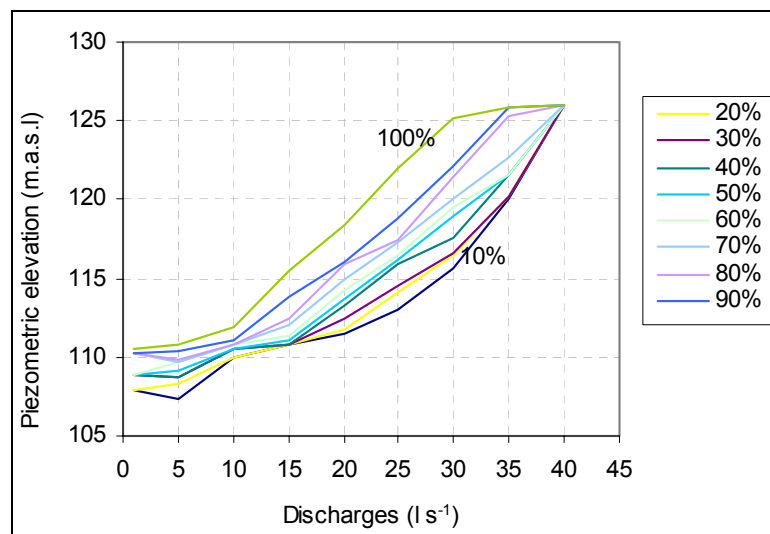


Fig. 8. Indexed characteristic curve of the pilot irrigation network

The indexed characteristic curves are an important tool for the construction of the variable speed pumping station. They are the basic data for variable operation since variable speed operation are associated with demand curve. For variable speed analysis, 90% demand curve has been chosen. This means that 90% of the configurations will be fully satisfied in pressure and hence the same percentage of configurations will be always satisfied even when discharge decreases or increases.

In Fig. 9, the characteristic curves of the pumps are shown when they are operating in parallel. Set points always drop on the demand curve. As the demand of the irrigation network increases, inverter modifies the pump speed according to minimum required pressure for the given discharge at the pumping station level, and pumps will again meet the pressure head requirement.

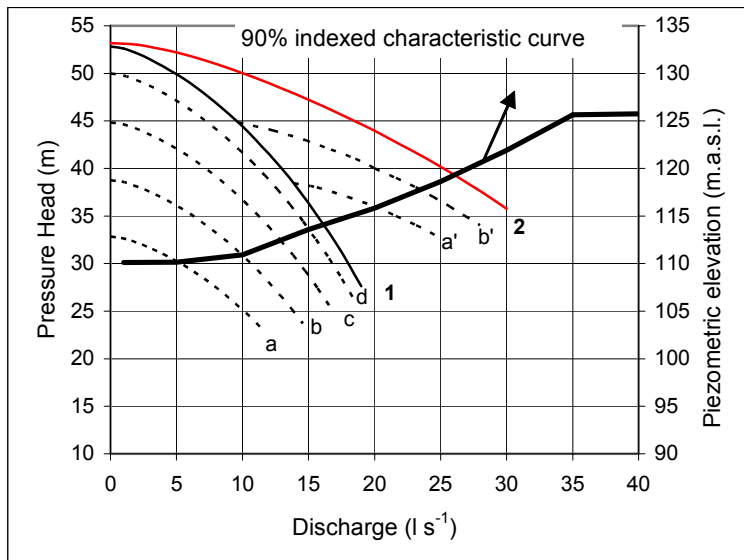


Fig. 9. Characteristic curves of the variable speed pumping station and the 90% indexed characteristic curve of the network.

Curve 1 is the curve of a single pump at 2930 rpm and curve 2 is the characteristic curve that are obtained from the simultaneous operation of two pumps at 2930 rpm. The dotted lines a,b,c, and d represent the modification of the curve 1 when the pump speed changes to 2310, 2510, 2700, and 2850 rpm, respectively. In the same way, the lines a' and b' are the curve of the two pump when the pumps are operating at 2930+2500 and 2930+2700 rpm. The figure shows that after  $16 \text{ l s}^{-1}$ , second pump will start to operate.

In order to validate the indexed characteristic curve model under operating conditions, some configuration analysis of hydrants were done. A certain number of random configurations of 1,2,3,4 and 5 hydrants simultaneously operating were selected. Discharge, upstream pressure head, and pump speed were measured for each configuration. The results obtained from the observations are reported together with maximum, minimum and 90 % demand curves in Fig. 10.

The figure shows that almost all the observed points fall on the 90 % demand curve (or very close to it) until  $16 \text{ l s}^{-1}$ . For higher discharge, pressure heads are higher (about 3 m) respect to the simulated values. It implies that variable speed operation should be better calibrated for two pumps when they operated together in parallel. Results show that pump output can reasonably match the desired need.

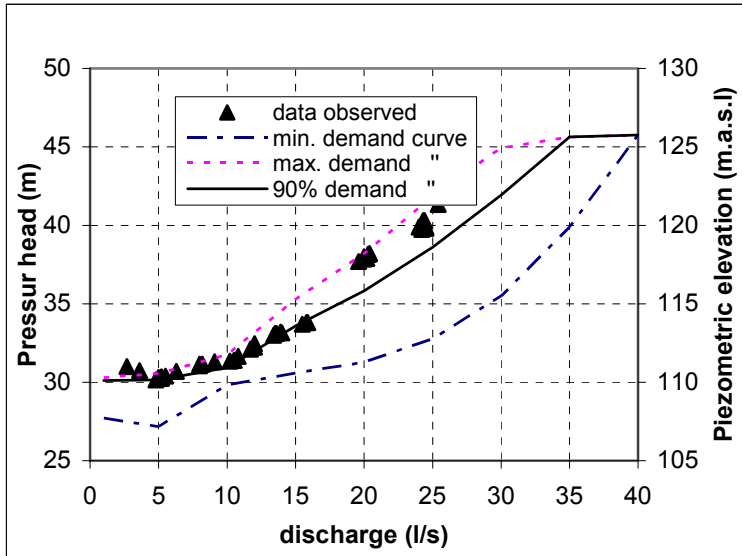


Fig. 10. Discharge and pressure head observed through variable speed operation.

### Power requirement

The comparison of power requirement for both types of operation is illustrated in Fig. 11. Main saving can be achieved at  $5 \text{ l s}^{-1}$ . At  $16 \text{ l s}^{-1}$ , power requirement is the same for both operations (Fig. 9). For discharge of  $15 \text{ l s}^{-1}$  power saving is minimum (0.53 kW).

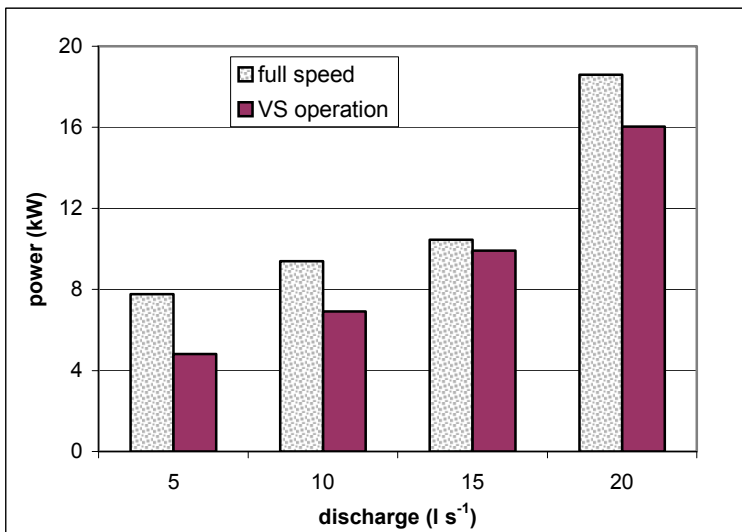


Fig. 11. Motor power required at full speed and in variable speed operation

### Energy requirement

Energy consumption by pumping station is calculated using equation 9. The absorbed power by for different discharges and the operation time were used to compute energy use. *Table 1* shows the energy requirement for constant speed operation while *Table 2* shows requirements for VS operation.

Table 1. Energy consumption of constant speed operation at various discharges.

Q, [l/s]	Operation time [h]	Pa [kW]	Motor Load [%]	E, [kWh]	E, [%]
5	704.27	7.76	70.5	5464.8	65.8
10	253.89	9.39	85.3	2384.0	27.7
15	34.28	10.45	95	358.2	4.3
20	4.90	18.59	84.5 - 84.5	91.1	1.0
TOTAL	997.34			8298.2	100

Table 2. Energy consumption of variable speed operation at various discharges.

Q, [l/s]	Operation time [h]	Pa [kW]	Motor Load [%]	E, [kWh]	E, [%]
5	704.27	4.82	43.8	3394.38	60.9
10	253.89	6.91	62.8	1754.38	31.5
15	34.28	9.92	90.1	340.05	6.1
20	4.90	16.03	94.2-51.6 <sup>2</sup>	78.54	1.4
TOTAL	997.34			5567.35	100

Table 3. Energy and power savings with variable speed operation in comparison with full speed operation.

Q, [l/s]	Operation time, [h]	Pa savings, [kW]	Energy savings, [kWh/year]	Energy savings, [%]
5	704.27	2.94	2070.44	37.9
10	253.89	2.48	629.64	26.4
15	34.28	0.53	18.17	5.1
20	4.90	2.56	12.55	13.8
TOTAL			2730.8	32.9

Table 3 shows that energy and power savings through variable speed operation were compared with constant speed operation. According to Table 3, total energy saving is about 2731 kWh/year, equal 32.9% of energy consumed by constant speed operation.

It is worth to mention that energy requirement changes according to flow rates. The amount of energy saving depends on the characteristic curve of the network, the characteristic curves of the pump and operation time.

The total volume of irrigation water is about 23723 m<sup>3</sup> for whole irrigation season. Thus, using variable speed pumps, electric energy per unit water discharge is 0.234 kWh/m<sup>3</sup>, while for constant speed operation is 0.349 kWh/m<sup>3</sup>. Therefore, by using variable speed pumping station, 0.116 kilowatt-hours of energy are saved per unit m<sup>3</sup> water pumped.

<sup>2</sup> After 16 l s<sup>-1</sup>, two pumps operate together. Therefore, there are two values showing motor loads separately (Maximum motor power was considered 11 kWh according to label of motor).

## Energy cost

The designer will select the system with minimum cost, which meets the farmer's requirements. In other words, the proposed approach must be financially worthwhile to apply. Annual energy savings is the difference in energy cost between constant speed operation and variable speed operation. This difference depends on the decrease in absorbed power at the reduced speed. The following relationship is used to calculate annual cost savings.

$$\text{Annual cost savings, €/year} = \text{Energy saved, kWh/year} \times \text{utility charge} \quad (10)$$

The average cost for pumping in the irrigation location is € 0.163 per kWh. Therefore, the average annual energy cost savings is:

$$\text{Annual cost savings} = 2730.8 \text{ kWh/year} \times € 0.163 = 445.12 \text{ €/year} \quad (11)$$

The formula above can only make comparisons between operating energy costs. In order to make a real assessment, capital costs of the systems should be considered together with operating costs. They will vary from country to country. Hence, the cost should be determined for local conditions.

Inverter represents the main difference in terms of investment cost between variable speed operation and constant speed operation. It costs about 3475 Euro in Italy. Thus, under the simplified hypothesis of constant return rate the payback period may be calculated as follow:

$$\text{Payback period} = \text{Cost of inverter/Annual energy cost savings} \quad (12)$$

As a result, repayment period reaches to 7.8 years. Even this value seems a little bit high; it may be considered as normal in a small scale, such as study area. However, payback period may be short in this study. For instance, by higher efficiency of pump and motor for various speeds, energy savings may be increased. Big savings may be achieved with higher application or with application that has longer operation time. Besides, there are also financial factors to take into consideration such as:

- current energy prices
- increase in energy prices during the pumping system life time
- interest rate
- estimated lifespan of equipment life.

## CONCLUSIONS

Since power requirements of variable speed and constant speed pump operation were known, energy requirement has been calculated. Total energy saving of about 2731 kWh occurred for the operation time of about 997 hours; this is equal 32.9% of energy consumed by pumping station with constant speed operation. Using variable speed pumping station, the average of 0.116 kilowatt-hours of energy were saved per unit cubic meter of water pumped.

According to utility rate, total cost of operation has been cut 445 Euro. The average payback period expected in accordance with obtained results is 7.8 years. Financial analysis of the investment by using Net Present Value (NPV) method indicated that proposed approach is convenient. The payback period may appear quite long because the application was carried out in a very small irrigation system. By considering the obtained percentage of energy saving (33%) and the fact that the cost of the inverter does not way too much for big pumping station, the payback period is considerably shorter for large-scale irrigation systems.

## REFERENCES

- Bethery, J.(1990). Reseaux collectives d'irrigation ramifies sous pression. Calcul et fonctionnement, CEMAGREF, Etudes n. 6.
- Khadra, R., and Lamaddalena, N. (2005). Un modello per la generazione delle portate in una rete irrigua con esercizio a domanda. VIII Convegno nazionale AIIA "l'Ingegneria agraria per lo sviluppo sostenibile dell'area mediterranea".
- Lamaddalena, N., (1997). Integrated simulation modeling for design and performance analysis of on-demand pressurized irrigation systems. PhD, Dissertation. Technical University of Lisbon, Lisbon.
- Lamaddalena, N. and Sagardoy, J.A. (2000). Performance analysis of on-demand pressurized irrigation systems. Irrigation and Drainage Paper n. 59. F.A.O. Roma.