Energy saving in electric motors

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Introduction

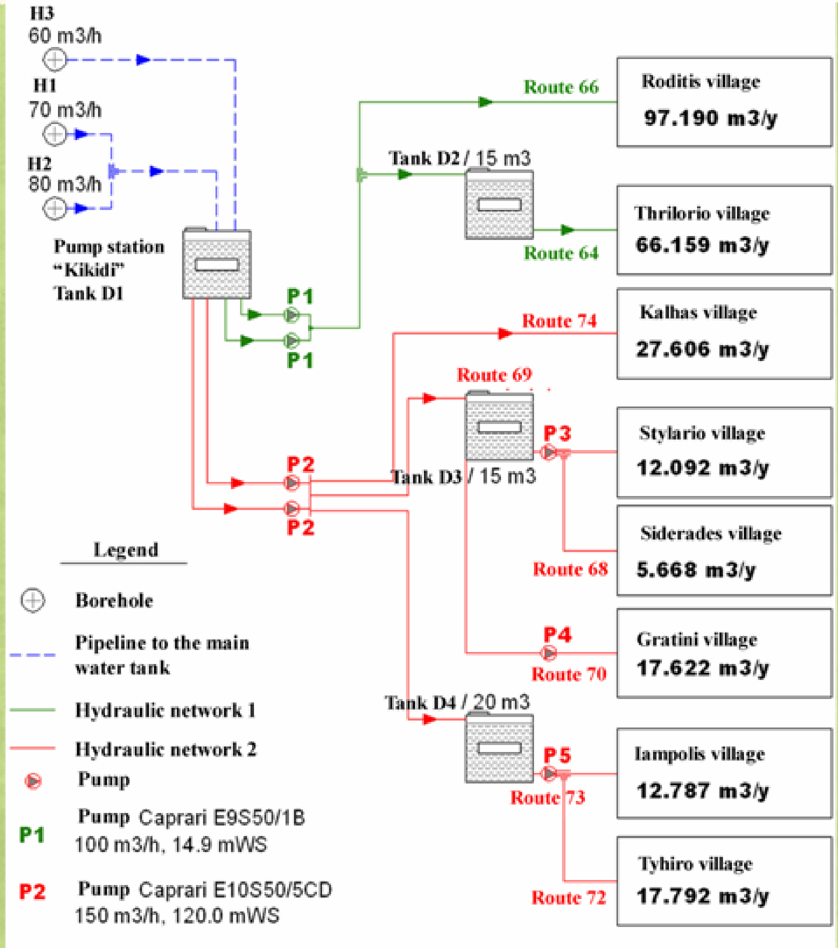
Generally

- Energy saving in pumping stations can be accomplished by applying the following measures:
  - installing inverters to control the flow of the pumps according to the demand, essentially to adjust the pumps to work at lower rotational speed than rated one
  - installing equipment to correct the power factor of the motors of the pumps (reactive power compensation).

Case study

- Energy saving in pumping station «Kikidi» of the County of Komotini, which consists of:
  - Three boreholes of 60m^3/h, 70m^3/h & 80m^3/h nominal flow, that supply the reservoir of the pumping station of 50m^3 capacity
  - The pumping station which is situated at the reservoir serves two separate networks (they will subsequently be referred to as "systems") as follows:
    - system 1: serves «Roditi» and «Thrylorio» settlements by two underwater pumps of 5,5kW rated power each (100m^3/h, 14,9mWS)
    - system 2: serves «Kalcha», «Stylario», «Siderades», «Gratini», «Iampolis» and «Tyxiro», by two underwater pumps of 66,0 kW rated power each (150m^3/h, 120mWS).
- The presentation is based on data of a study that was carried out by Mechanical Engineer Mr. Assariotaki Zacharia and joined the«Saving» action of Municipality of Komotini, funded by the EU and the Greek State.

Case study –
Flow diagram of the pumping station



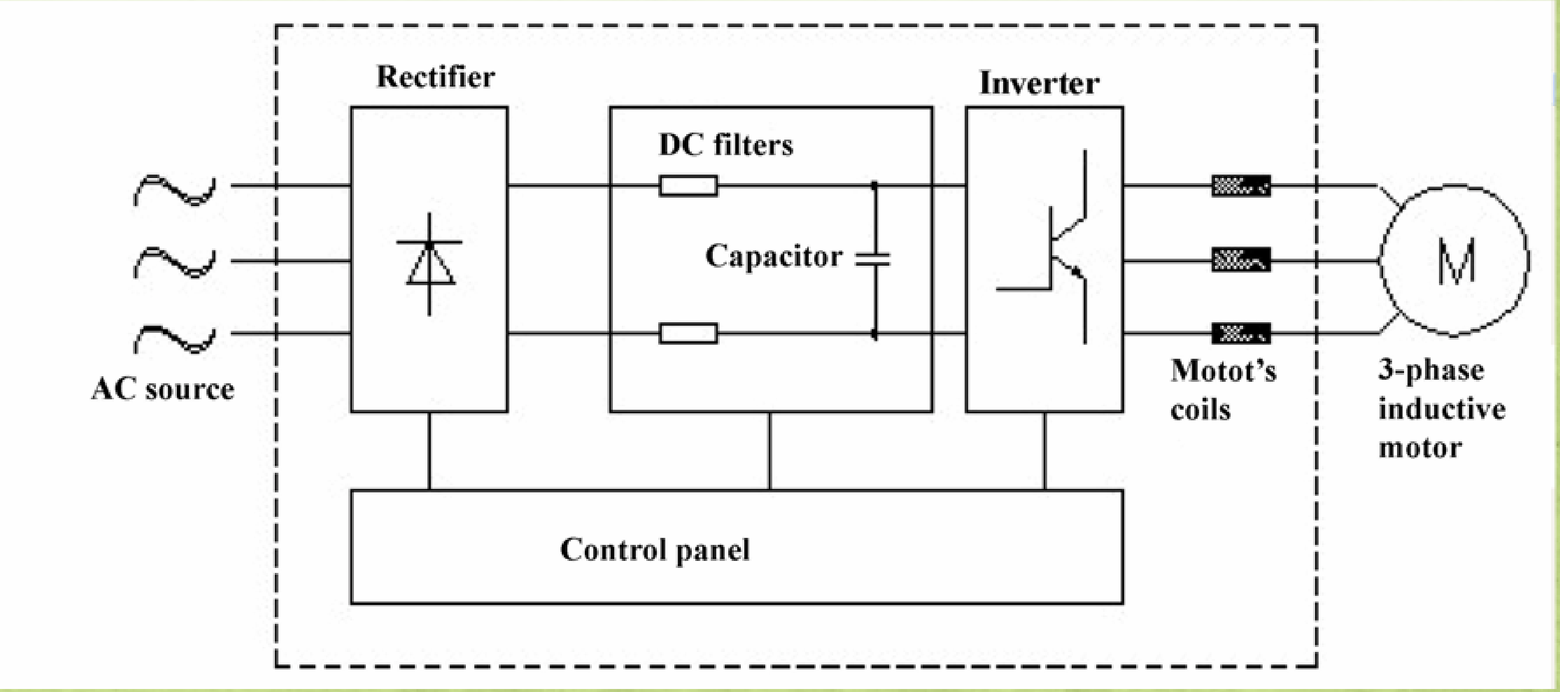
Suggested interventions

- Due to energy saving reasons, as well as smooth functioning of the pumps, it is suggested:
  - to install Variable Speed Drivers with up to 5th-grade harmonics compensating filters
  - to install capacitors to correct the power coeffficient.
- The above mentioned interventions concern both of each system, beside the fact that one of the two pumps is used as a back-up one.
- This, of course, is a disadvantage in economic evaluation of the investment.

Variable Speed Drivers

Variable Speed Drivers

- Variable Speed Drives – VSD or Variable Frequency Drives – VFD are used to control and adjust the rotation speed of a machine as desired.
- One usual VSD consists of three parts:
  - the motor
  - the inverter
  - the control system.



Variable Speed Drivers

- The motor is connected to the load.
- The AC passing through the inverter is converted into DC.
- Then a voltage waveform with variable width and frequency is created of DC.
- By using Pulse Width Modulation (PWM) technique the voltage and frequency is adjusted accorded to the requirements of the motor, which is controlled by the inverter.
- This way the revolutions and the voltage, essentially the operating power of the machine is adjusted.

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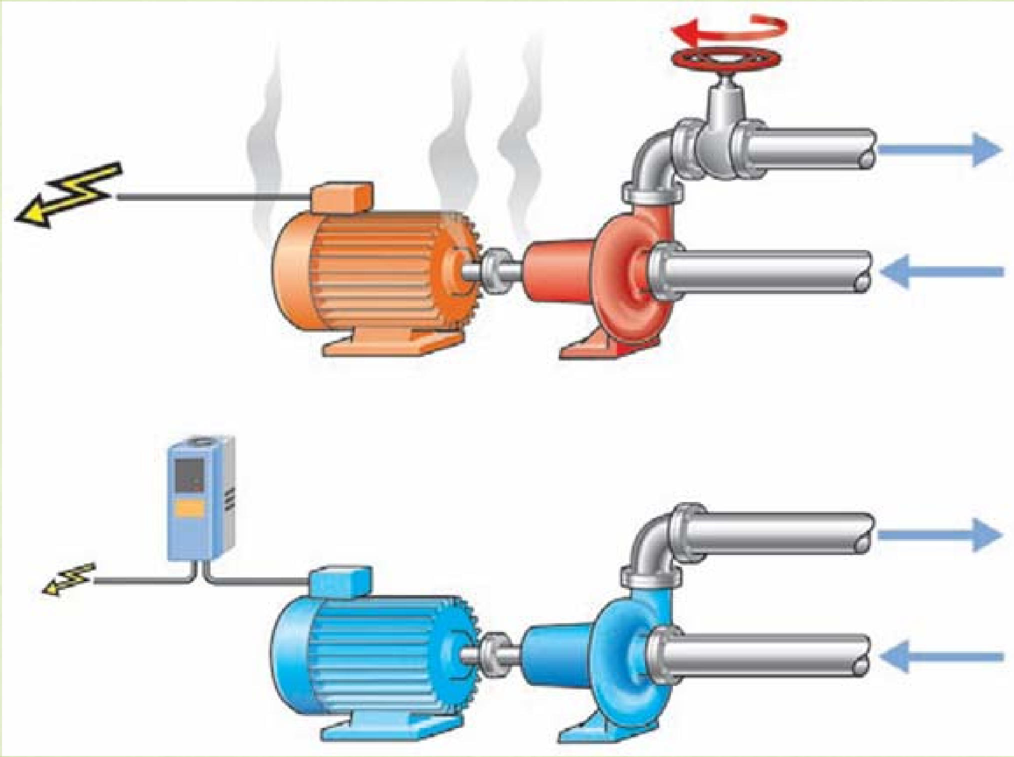
Variable Speed Drivers



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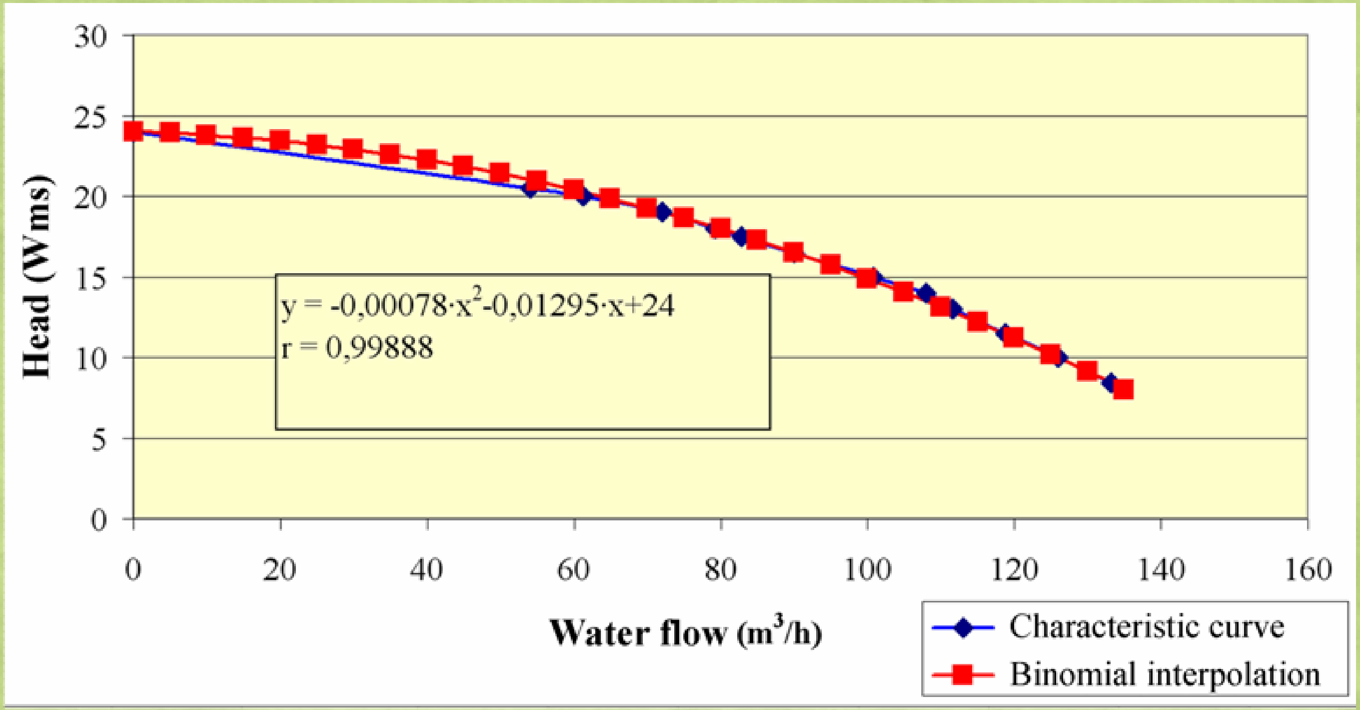
Existing situation

Technical specifications of installed pumps

Pump properties	System 1	System 2
Pump constructor	Caprari	Caprari
Type	E9S50 / 1B	E10S50 / 5CD
Runner type	Mixed flow	Mixed flow
Stages' number	1	5
Rotational speed (rpm)	2.900	2.900
Flow (m^3/h)	100	150
Net head (mWS)	14,9	120,0
Motor power (kW)	5,5	66,0
Efficiency at 75-100% of the load (%)	75,0 – 75,5	88,0 – 87,5
Power factor at 75-100% of the load (%)	0,715 – 0,795	0,795 – 0,835

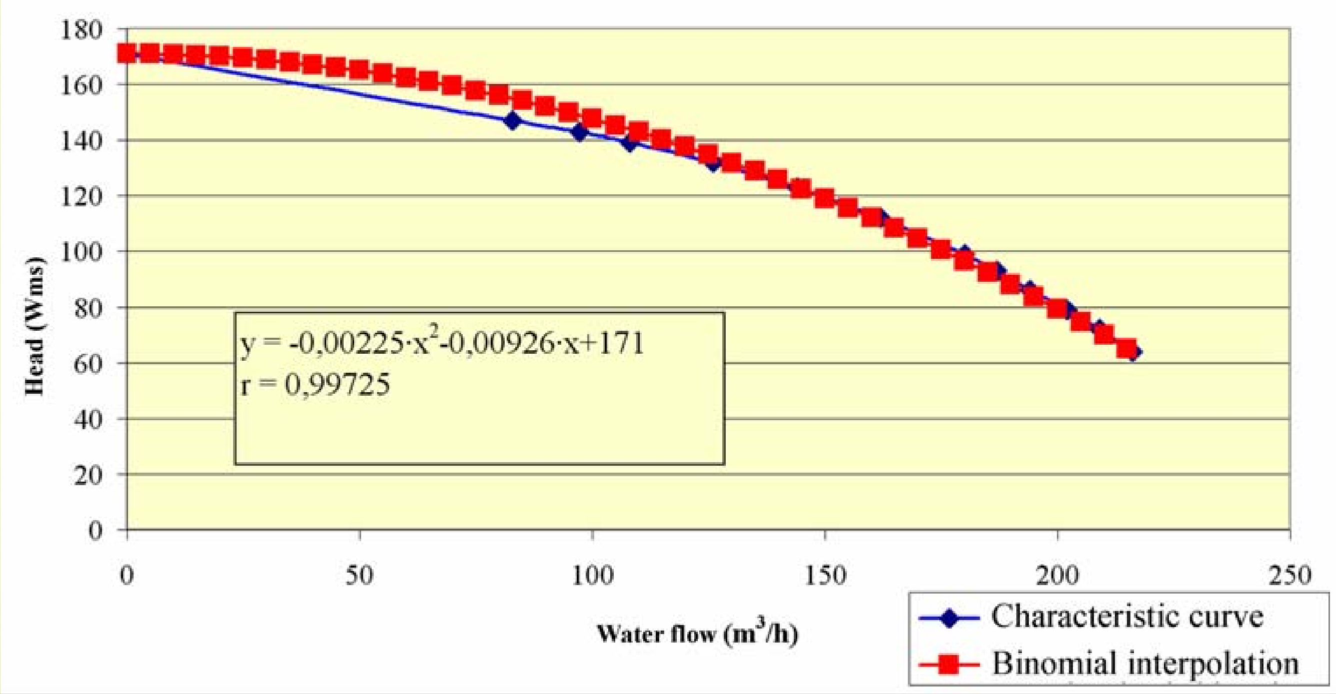
Net head - flow characteristic curve of the E9S50 / 1B pump

Net head – flow characteristic curve for the E9S50 / 1B pump and for the nominal rotation speed n=2.900rpm													
Q (m^3/h)	0	54,0	61,2	72,0	79,2	82,8	90,0	100,8	108,0	111,6	118,8	126,0	133,2
H (mWS)	24,0	20,5	20,0	19,0	18,0	17,5	16,5	15,0	14,0	13,0	11,5	10,0	8,4



Net head - flow characteristic curve of the of the E10S50 / 5CD pump

Net head – flow characteristic curve for the E10S50 / 5CD pump and for the nominal rotation speed n=2.900rpm													
Q (m^3/h)	0	82,8	97,2	108	126	144	162	180	187	194	202	209	216
H (mWS)	171	147	143	139	132	123	112	99	93	86	79	72	64



Quadratic interpolation and pumps' similarity

- The curves of the pumps are approximated by quadratics by applying classical arithmetical methods (Langrange or Newton interpolation).
- The generic form of the polynomial interpolation which is applied on the curves is :

  $H = a \cdot Q2 + b \cdot Q + c$

- The polynomials that we come to after applying the above interpolation methods, shown in curve diagrams of the next slide, are:
  - for the E9S50 / 1B pump: $H = -0{,}00078 \cdot Q^2 – 0{,}001295 \cdot Q + 24$
  - for the E10S50 / 5CD pump: $H = -0{,}00225 \cdot Q^2 – 0{,}00926 \cdot Q + 171$.
- The above shown quadratic interpolations apply to the specific characteristic curves of the pumps, which means for rated operating rotational speed (n=2.900rpm).

Quadratic interpolation and pumps' similarity

- For the pumps' operation at different rotational speeds, let's say n´, then operation curves will come up (Q´,H´).
- Based on similarity formulas of the pumps:

$$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right) \& \frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2$$

it can be easily proven that for the two pumps the quadratic interpolation:

$$H' = a \cdot Q'^2 + b \cdot \left(\frac{n'}{n_r}\right) \cdot Q' + c \cdot \left(\frac{n'}{n_r}\right)^2$$

will apply , where

a, b, c are the quadratic parameters that have been calculated for rated rotational speed

n_r=2.900rpm the rated rotational speed of the pumps.

Quadratic interpolation and pumps' similarity

- The last relation can be written as a polynomial of 2nd degree versus the rotational speed of the pumps n´.

$$\frac{c}{n_r^2} \cdot n'^2 + \frac{b \cdot Q'}{n_r} \cdot n' + \left(a \cdot Q'^2 - H'\right) = 0$$

- By using the above shown relationship the rotational speed of the pump for varied flow and net head of the pumping station can be calculated.

Annual water consumption

- According to the municipal water supply service the recorded water consumptions are 65% of pumped water quantity.
  The non recorded water consumptions are referred to network losses and measurement errors of the hydrometers.
- Average daily water consumptions:
  - system 1: 688,5m^3/day
  - system 2: 394,4m^3/day

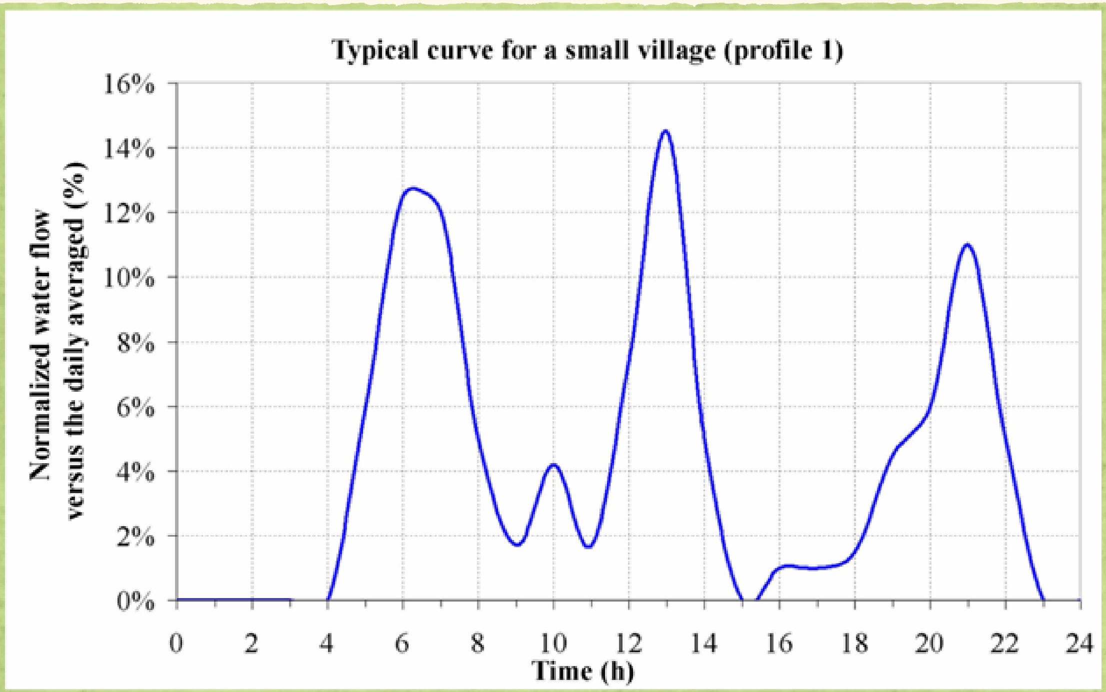
No	Settlement	Recorded water consumption 2008 (m^3)	Total water consumption 2008 (m^3)
1	Roditis	97.190	149.523
2	Thrylorio	66.159	101.783
	Total 1:	**163.349**	**251.306**
3	Kalchas	27.606	42.471
4	Stylario	12.092	18.603
5	Siderades	5.668	8.720
6	Gratini	17.622	27.111
7	Iampolis	12.787	19.672
8	Tyxiro	17.792	27.372
	Total 2:	**93.567**	**143.949**

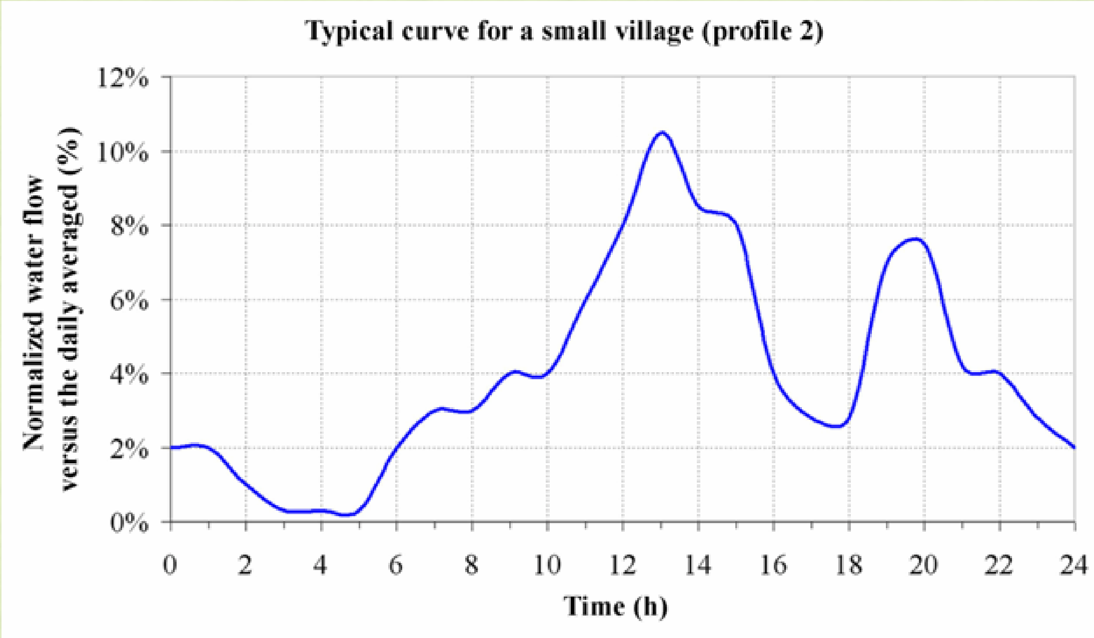
Daily water consumption variation

- To calculate the energy saving because of the adjustment of the operating rotational speed of the pumps with the support of inverters, it is necessary to know the annual time series of mean hourly values of water flow demand.
- For this reason, due to the lack of measurement data, two different daily profiles of water flow demand are employed, based on relevant literature ("Pumps". Group of Mechanical and Electrical Engineers of Northen Greece, 1985).
- These profiles refer to a small village and a town respectively.

Hour of the day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Small village (profile 1) (%)	0,0	0,0	0,0	0,0	6,0	12,5	12,0	5,0	1,7	4,2	1,7	7,4	14,5	5,0	0,0	1,0	1,0	1,5	4,5	6,0	11,0	5,0	0,0	0,0
Town (profile 2) (%)	2,0	1,0	0,3	0,3	0,3	2,0	3,0	3,0	4,0	4,0	6,0	8,0	10,5	8,5	8,0	4,0	2,8	2,8	7,0	7,5	4,2	4,0	2,8	2,0

Daily water consumption variance





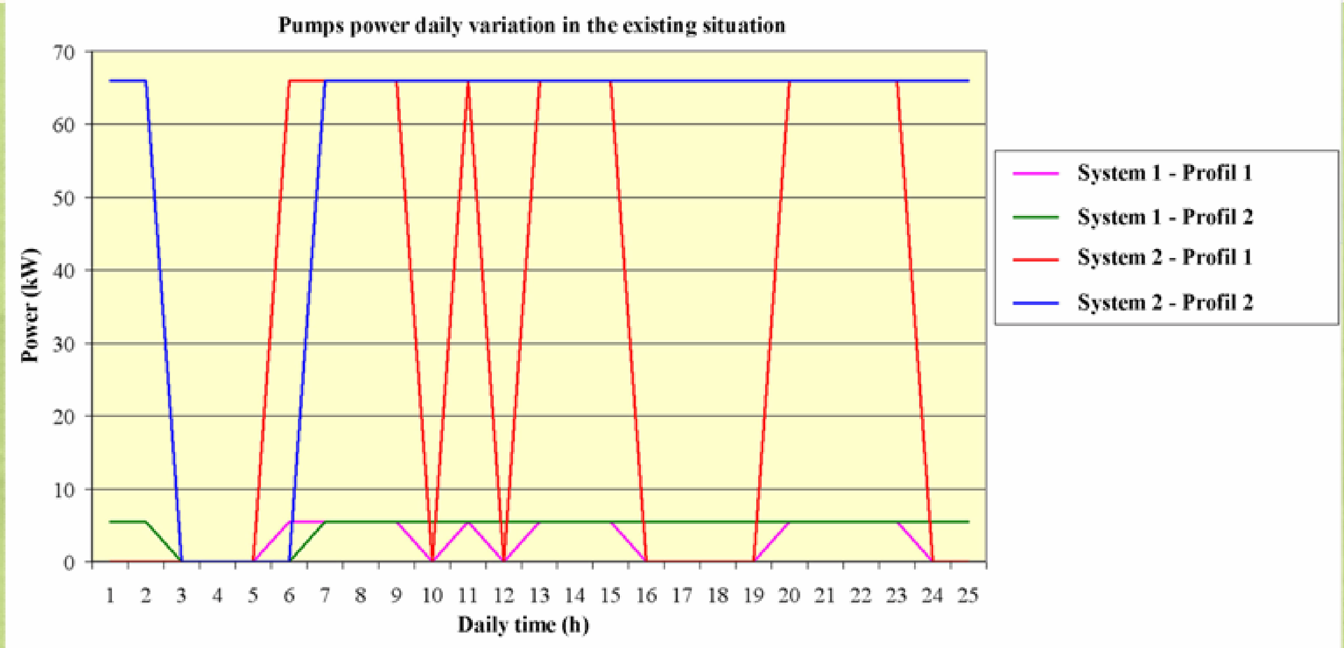
Existing electrical energy consumption

- To calculate the existing electricity consumption it is assumed that the pumps work when the average water flow demand becomes greater than 2% of the average daily water consumption.

- In this case, in existing situation, lacking the capability to adjust the rotational speed of the pumps, whenever they start to operate, they operate at rated power, which means:
  - for the E9S50 / 1B pump: N_1 = 5,5kW
  - for the E10S50 / 5CD pump: N_2 = 66,0kW.

- Based on the above mentioned, the daily operation power variation of the pumps in existing situation is calculated.

Existing electricity consumption



	System 1		System 2	
	Profile 1	Profile 2	Profile 1	Profile 2
Daily energy consumption (kWh)	66	116	792	1.386
Annual energy consumption (kWh)	24.090	42.158	289.080	505.890

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Energy consumption and saving after integrating inverters

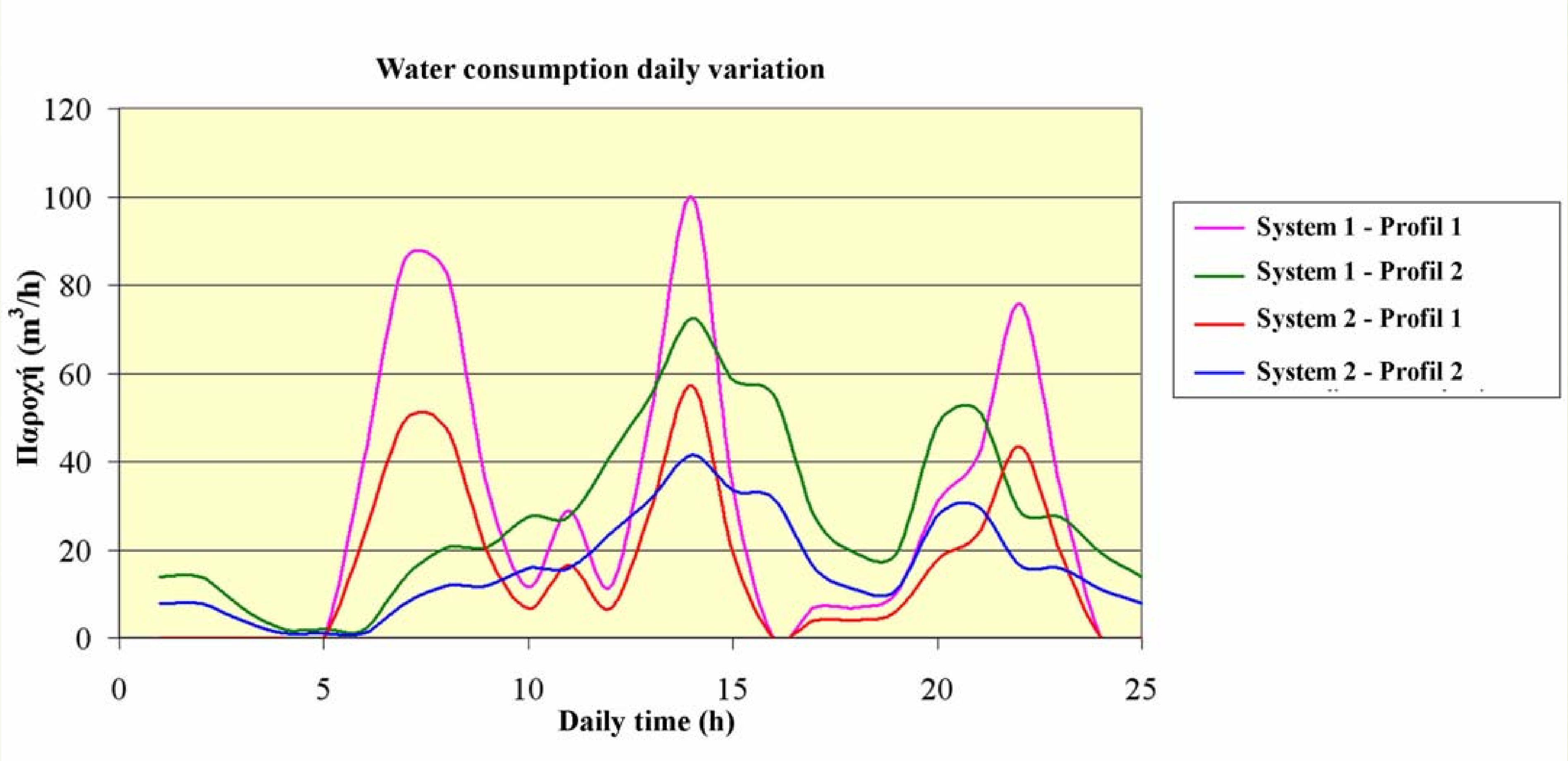
Adjusting revolutions of the pumps after integrating inverters

- After integrating inverters it is possible for the pumps to operate at different than rated rotational speed, depending on the water flow demand.
- In this case, for variable flow Q and assuming, approximately, the pumping net head to be constant, it is possible to calculate the required rotational speed of the pumps, using the general relation:

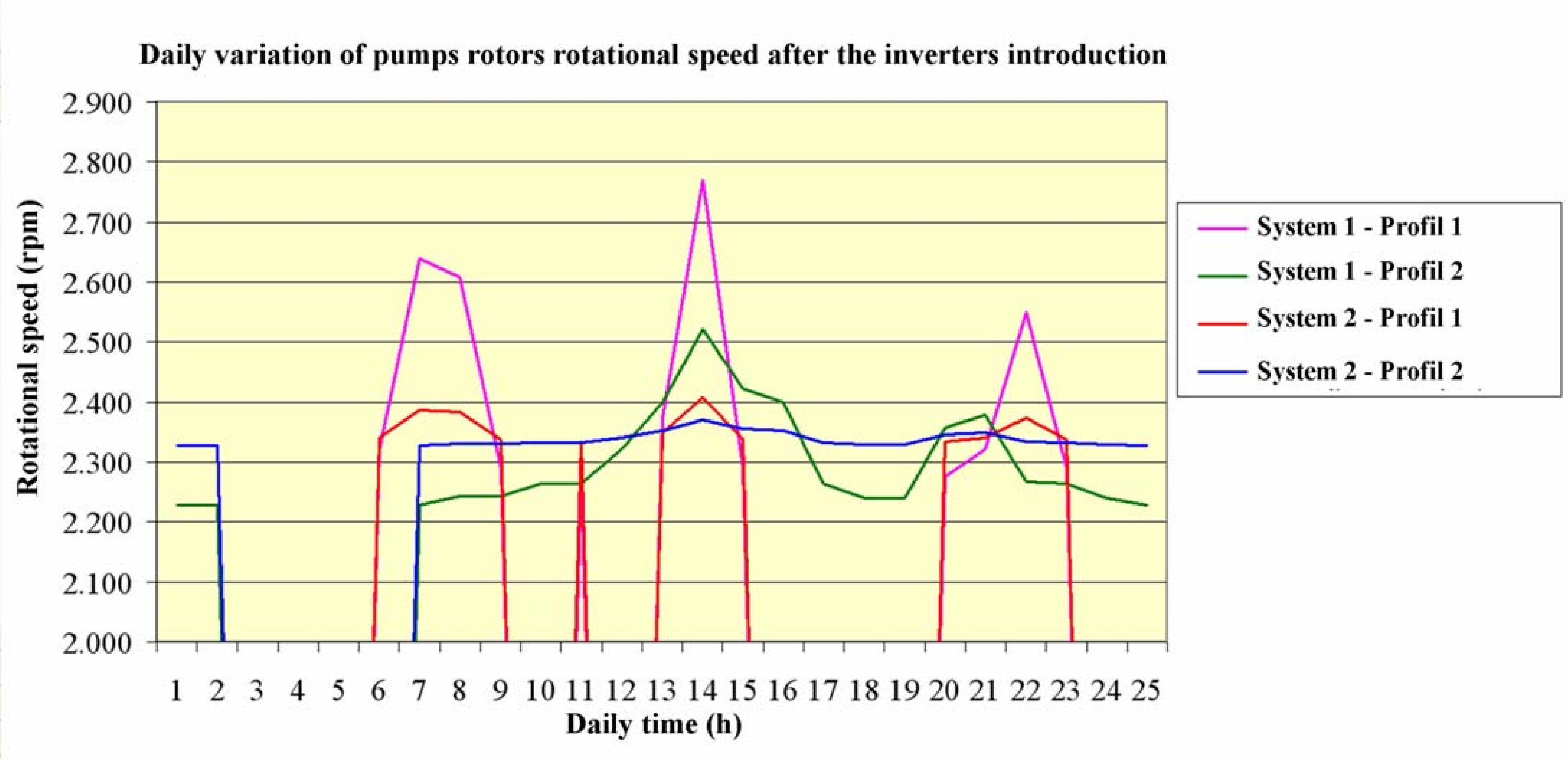
$$\frac{c}{n_{ov}^2} \cdot n'^2 + \frac{b \cdot Q'}{n_{ov}} \cdot n' + \left(a \cdot Q'^2 - H'\right) = 0$$

  where a, b, c are the quadratic parameters for each pump separately, Q΄ the varied water flow, which come up from water flow daily profiles presented previously and H΄ the constant net head of each pumping station (14,9m και 120m).
- Actually, as the water flow changes , the flow losses in tubes change too, consequently the total net head of the installation changes as well.

Daily water flow demand curves



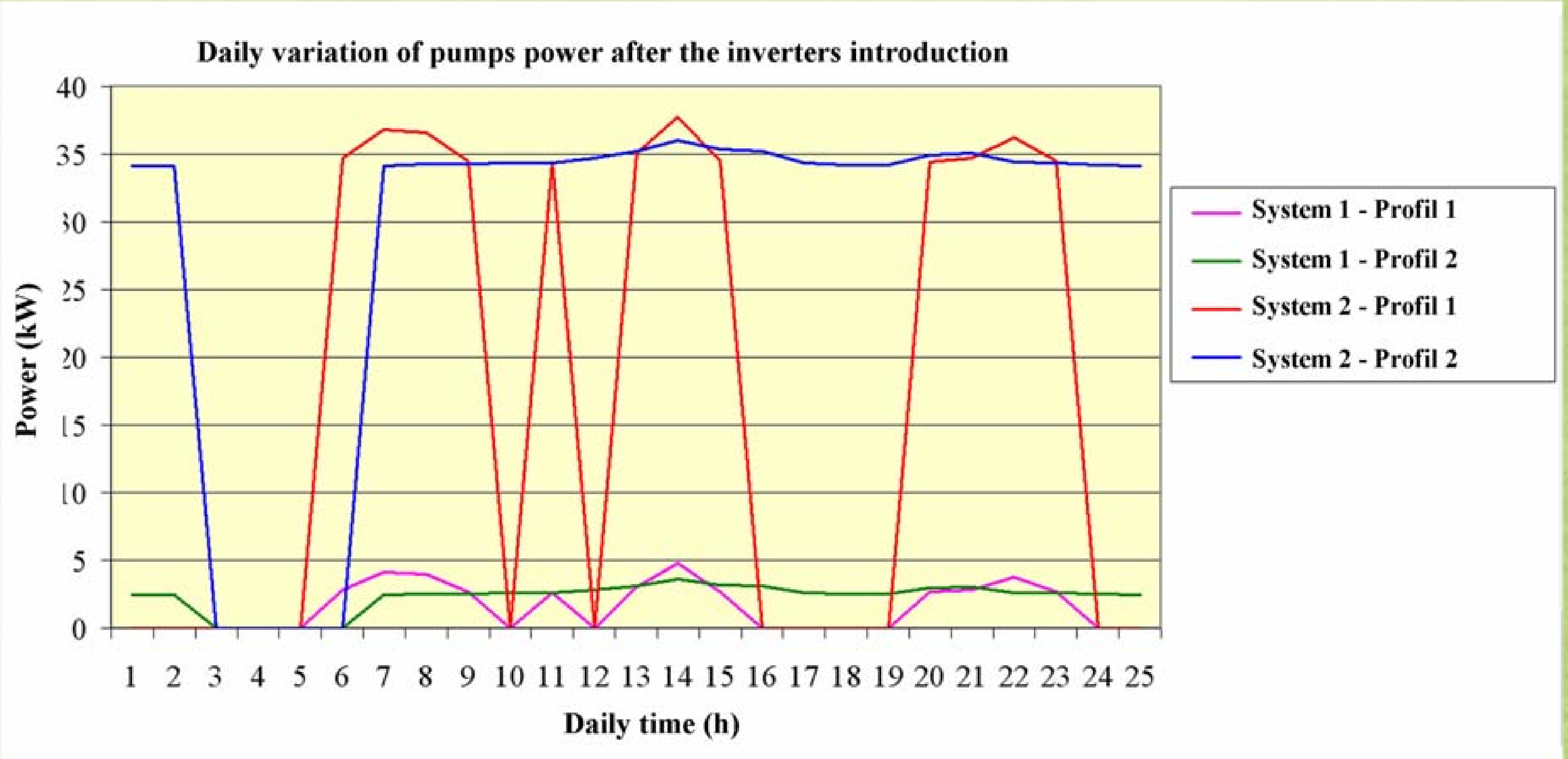
Daily water flow demand curves



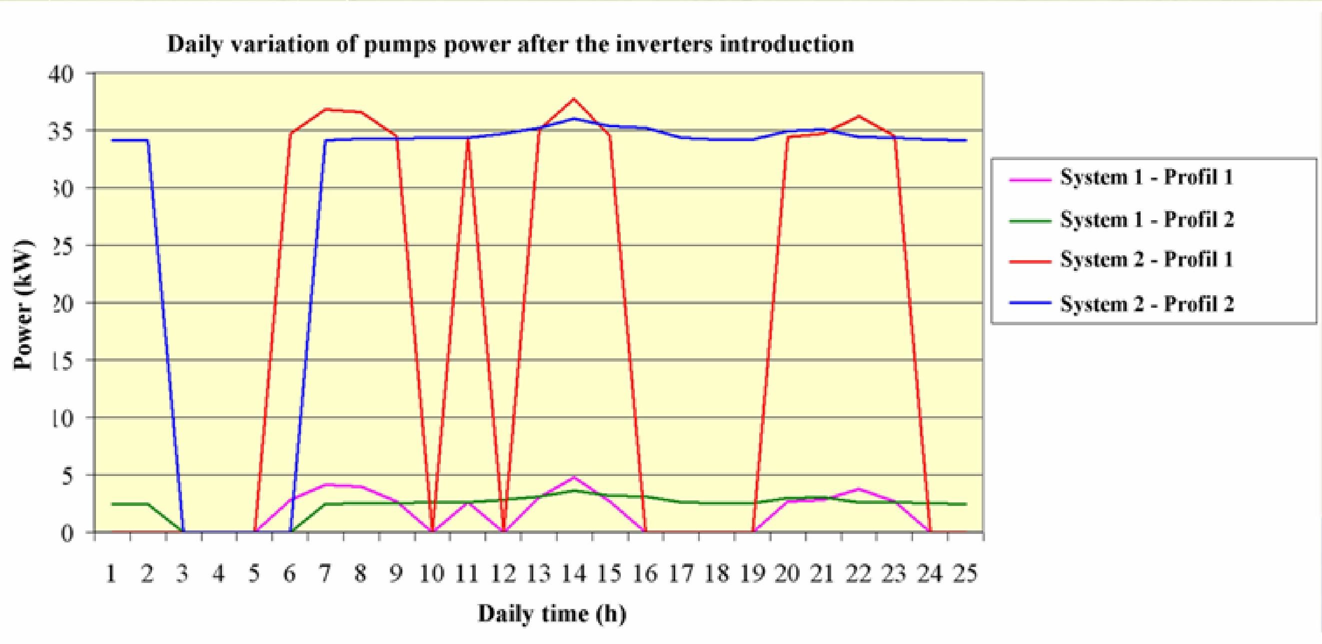
Operating power of the pumps versus the rotational speed

- Having calculated the operating rotational speed of the pumps, the power consumption come up from the pumps' similarity laws:

$$\frac{N'}{N_{ov.}} = \left(\frac{n'}{n_{ov.}}\right)^3$$



Electricity consumption after integrating inverters



	System 1		System 2	
	Profile 1	Profile 2	Profile 1	Profile 2
Daily energy consumption (kWh)	39	58	424	726
Annual energy consumption (kWh)	14.143	21.025	154.861	265.033

Electricity saving after integrating inverters

Method	System 1		System 2	
	Profile 1	Profile 2	Profile 1	Profile 2
Annual water consumption (m^3)	251.306		143.949	
Existing annual electricity consumption (kWh)	24.090	42.158	289.080	505.890
Annual electricity consumption after integrating inverters (kWh)	14.143	21.025	154.861	265.033
Annual electricity saving (kWh)	9.947	21.132	134.219	240.857
Annual electricity saving percentage (%)	41,29	50,13	46,43	47,61
Specific existing electricity consumption (kWh/m^3)	0,0959	0,1678	2,0082	3,5144
Specific electricity consumption after integrating inverters (kWh/m^3)	0,0563	0,0837	1,0758	1,8412
Total annual electricity saving in both systems (kWh)	Profile 1		Profile 2	
	144.166		261.989	

Compensating reactive power with capacitors

Suggested compensation

- Due to the load size and the autonomous operation of the pumps, local compensation for each pair of pumps is suggested.

- The power of the capacitors is calculated by using the following relation:

$$Q_c = P \cdot \left[\frac{\sqrt{1-\cos^2\varphi_1}}{\cos\varphi_1} - \frac{\sqrt{1-\cos^2\varphi_2}}{\cos\varphi_2} \right] \Leftrightarrow Q_c = P \cdot \left(\tan\varphi_1 - \tan\varphi_2 \right)$$

where:

Q_C: the required total reactive power of the capacitors

P: active power consumption by the pumps

$\cos\varphi_1$: power coefficient of the existing facility

$\cos\varphi_2$: the corrected power coefficient of the system after the compensation.

Capacitors reactive power

Magnitude	System 1	System 2
Pump rated power (kW)	5,5	66,0
Initial power coefficient $\cos\varphi_1$ (75 – 100% of the load)	0,715 – 0,795	0,795 – 0,835
Corrected power factor $\cos\varphi_2$	0,98	0,98
Required capacitive power (kVAR)	4,3 – 3,1	37,0 – 30,1
Rated capacitive power of the capacitors (kVAR)	5	40

- During capacistors' purchase , it should be checked that the power of the capacitors doesn't exceed 90% of reactive power at motor's open circuit operation, otherwise, self-excitation of the motor may occur in case of its disconnection from the network.

Harmonic oscillation compensating filters

- Due to the installation of Variable Speed Drivers at pumps motors, harmonic oscillations that can destroy the capacitors may be created.
- For this reason , it is suggested to install harmonic oscillation compensating filters in the network.

Reactive energy saving

- From now on , the calculations will be made using the profile 1 of water flow demand, which seems to be more realistic for the region of study, besides it is presented as the most conservative regarding energy saving percentage.
- The reduction of reactive energy that will be accomplished by using capacitors is calculated by using the following relation:

$$\tan\varphi = \frac{A}{W}$$

where:

- A: reactive energy (kVARh)
- W: consumed active energy by active power demand (kWh).

Reactive energy saving

- Assuming the initial power factor to be as defined by the manufacturer in the machine's specs list for the 75% of load, the following table comes up:

Magnitude	Without inverter		With inverter	
	System 1	System 2	System 1	System 2
Annual electrical energy consumption (kWh)	24.090	289.080	14.143	154.861
Initial power factror cosφ1	0,715	0,795	0,715	0,795
Annual reactive energy consumptions in existing operation (kVARh)	23.555	220.577	13.829	118.164
Final power factor cosφ2	0,98	0,98	0,98	0,98
Annual reactive energy consumption after compensation (kVARh)	4.892	58.700	2.872	31.446
Annual reactive energy saving (kVARh)	18.663	161.877	10.957	86.718
Annual reactive energy saving percentage (%)	79,23	73,39	79,23	73,39

Total energy saving after integrating inverters and capacitors

- The total reactive energy saving, taking into consideration the existing operating and the final situations that will come up after integrating inverters and capacitors is:

Magnitude	System 1	System 2
Annual reactive energy consumption in existing situation (kVARh)	23.555	220.577
Annual reactive energy consumption after compensation and inverters integration (kVARh)	2.872	31.446
Annual reactive energy saving (kVARh)	20.683	189.131
Annual reactive energy saving percentage (%)	87,81	85,74

Economical indexes of the project

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Initial cost of interventions

No	Description	Costς (€)
1	Purchase and installation of automation panel of the pumps that includes: a. two inverters for pumps of 5,5kW power with alternating operation b. up to 5^{th} degree harmonic oscillations filter c. capacitors of up to 5kVAR power	5.300
2	Purchase and installation of automation panel of the pumps that includes: a. two inverters for pumps of 66,0kWpower with alternating operation b. up to 5^{th} – degree harmonic oscillations filter c. capacitors of up to 40kVAR power	23.000
	Total	28.300

In above mentioned prices V.A.T. of 23% is included.

Payback time period

Total investment cost (€)	28.300
Annual energy saving (kWh)	144.166
Annual energy saving cost (€)	16.621
Payback time period (years)	1,70
Specific cost per unit of saved energy (€/kWh)	0,1963

Electricity price: 0,11529€/kWh

End of presentation

Thank you for your attention