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Determination of Global Efficiencies of Variable Speed Pumps within Water Supply Systems

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Abstract – **The energy transformations involved in the operation of the pumping installations are carried out by pumping aggregates consisting of an electric motor and a pump. In order to provide a full adaptation to the users' variable demands, variable speed motor driven pumps are used on networks (such motors being equipped with frequency converters). The paper presents a method for determining the global efficiency of a frequency converter-asynchronous motor-pump group. The method has been implemented at the Chirița Pumping Station, main facility within the Iasi City water supply system.**

Keywords – efficiency, pumps, static frequency converters, water supply

1. INTRODUCTION

As regards the pumps operation the pursued objective is to maximize the overall efficiency of the electrical energy-to-hydraulic energy conversion process, while complying to functional restrictions imposed by the users of the hydraulic system in which these are integrated. The achieving of this goal requires a permanent control of the assembly's performance by measuring the status parameters which are involved in the analysis [1].

Usually pumping stations serve networks in which demands vary over time between a minimum flow rate and a sizing flow rate. The variation of a pumped flow can be provided by means of two methods [2]:

- by modifying the system's head characteristic, reduced at delivery's origin by:
  - modifying of head loss characteristic on pumps communications;
  - modifying of pumps' own head loss characteristics;
  - modifying of the resulting characteristic of a pumping group equipped with parallel coupled pumps;
- by an intermittent pumping and flow compensation, by providing the head demanded by network.

In pumping installations within water supply systems, the changing of a pump characteristic is achieved by varying the speed of the pumps rotors, this being obtained by variable speed drives (on serial-built asynchronous motors), by means of static frequency converters. This control system can be efficient only if the subsequent power savings (obtained on a normed time of pump operating) will cover al least the costs of such pump driving systems.

2. THEORETICAL ASPECTS

In order to study the efficiency of variable speed pump drives there is need to take into account the efficiency modification for three components [2]:

- efficiency of the pump (η_{tb});
- efficiency of the static frequency (η_{csf});
- efficiency of the converter-driven asynchronous motor (η_{ma}).

2.1. Method for determining the global efficiency of the pumping group: static frequency converter – asynchronous motor – pump

The diagram of a variable speed pumping group driven by static frequency converter is shown in Fig. 1.

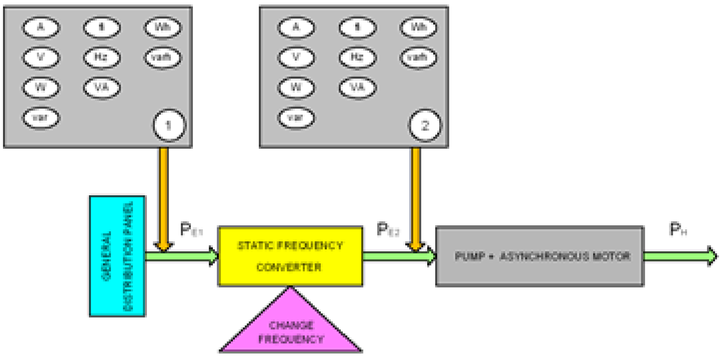


Fig. 1. Diagram of a variable speed pumping group driven by static frequency converter (static frequency converter - asynchronous motor - pump)

The efficiency of a pumping system (that is, pump + asynchronous motor) driven by converter is given by equation (1):

$$\eta_{AP} = \frac{P_H}{P_{E2}} \tag{1}$$

The efficiency of a variable speed pumping group (pump driven by static frequency converter) is given as the equation (2):

$$\eta_{GP} = \frac{P_H}{P_{E1}} \tag{2}$$

The hydraulic power, given in kW, and exerted by pump towards the fluid is to be computed with equation (3):

$$P_H = 9{,}81QH \tag{3}$$

The electric power absorbed by the static frequency converter is given by (4):

$$P_{E1} = \sqrt{3} U_1 I_1 \cos\varphi_1 \tag{4}$$

where: U_1 – voltage of the current that feeds the static frequency converter; I_1 – intensity of phase current, corresponding to voltage U_1; $\cos\varphi_1$ – power factor.

The electric power absorbed by pump results from (5):

$$P_{E2} = \sqrt{3} U_2 I_2 \cos\varphi_2 \tag{5}$$

where: U_2 – voltage of current that feeds the driving motor; I_2 – intensity of current on phase corresponding to voltage U_2; $\cos\varphi_2$ – power factor.

Thus, the efficiency of the static frequency converter shall be given by (6):

$$\eta_{csf} = \frac{P_{E2}}{P_{E1}} \tag{6}$$

The diagram of a pumping group, provided with variable speed drive, which uses direct grid supplied power (without a static frequency converter), is shown in Fig. 2.

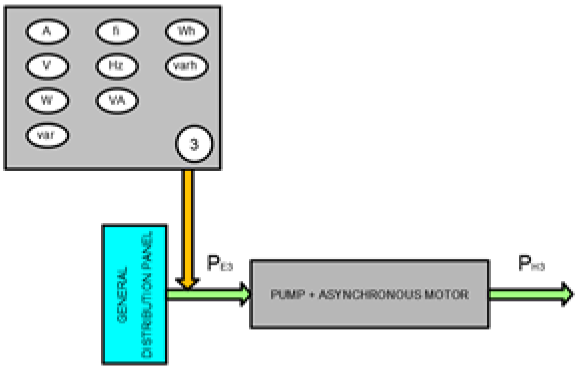


Fig. 2. Diagram of a static frequency converter - asynchronous motor - pump (power supplied directly from the grid)

In this case, the pump's efficiency is computed with equation (7):

$$\eta_{AP} = \frac{P_H}{P_{E3}} \tag{7}$$

$$P_{E3} = \sqrt{3} U_3 I_3 \cos\varphi_3 \tag{8}$$

where: U_3 – voltage of current that feeds the driving motor; I_3 – intensity of current on phase corresponding to voltage U_3; $\cos\varphi_3$ – power factor.

3. CASE STUDY: THE CHIRIȚA PUMPING STATION

By using the above-shown method it has been possible to compute the global efficiency of a pumping group having the configuration: *static frequency converter - asynchronous motor - pump*. Measurements have been carried out in the "CITY" pumping plant, a component of the main "Chiriţa" pumping station, located in Iaşi City (Photo 1).

The "CITY" pumping plant includes (2+1) WILO ASPV250C pumps featuring the next parameters: Q = 300 l/s and H = 48 mWC (Photo 2). The P1, P2 and P3 pumps are connected in parallel and are driven at nominal or variable speed by an ATV61HC22N4 static frequency converter (Photo 3), that is switcheable on all three pumps.

Photo 1. The Chiriţa pumping station

Photo 2. The "CITY" pumping plant

Photo 3. The static frequency converter

In the first phase, by measurements performed in direct coupling mode (without static frequency converters), the pumps' efficiencies η_{AP} were computed (for pumps within the "CITY" installation), the efficiencies depending on flows pumped towards the network.

The flow variation was achieved by closing the valves on the pumps discharge lines. The flow rates, corresponding to different operating modes, were visualized by means of SCADA software, software used for surveillance, control and data acquisition [3].

The pressures on the pumps' suction and discharge lines were read on the pressure gauges connected to the system pressure outlets. The electrical parameters were determined using the FLUKE 435 energy analyzer. All parameters involved in the analysis were measured after the stabilization of the operating mode.

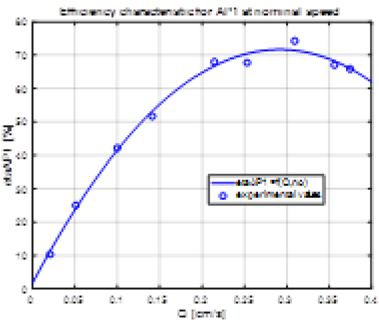
The measurements results were centralized in Table 1.

Table 1. Pumps' efficiencies, η_{AP}, within the "CITY" installation, in the case of direct grid power supply

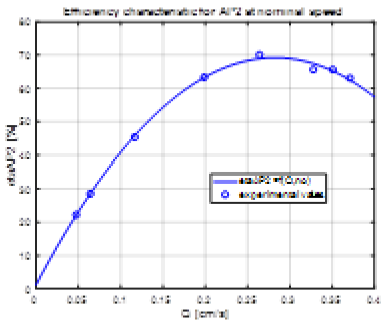
Pump	Q (m^3/h)	H (m)	U_3 (V)	I_3 (A)	$\cos\varphi_3$ (-)	P_H (kW)	P_{E3} (kW)	η_{AP} (%)
P1	1350	39,11	230	364	0,87	143,87	218,51	65,84
	1283	41,49	230	360	0,87	145,04	216,11	67,12
	1113	49,50	230	340	0,86	150,12	201,76	74,40
	912	54,29	229	337	0,86	134,93	199,11	67,77
	770	56,41	230	297	0,85	118,36	174,19	67,95
	509	58,11	230	269	0,84	80,60	155,91	51,69
	359	59,52	229	242	0,83	58,23	137,99	42,20

	183	60,99	229	220	0,80	30,41	120,91	25,15
	73	61,44	230	215	0,80	12,22	118,68	10,30
P2	1335	36,86	229	360	0,86	134,10	212,70	63,05
	1263	40,05	228	357	0,86	137,85	210,00	65,54
	1180	42,84	229	355	0,86	137,74	209,74	65,67
	952	49,71	229	315	0,85	128,97	183,94	70,11
	714	54,11	230	287	0,84	105,27	166,35	63,29
	420	56,67	230	250	0,83	64,86	143,18	45,30
	230	57,52	230	226	0,81	36,05	126,31	28,54
	170	58,49	230	220	0,80	27,10	121,44	22,31

Figure 3 shows the correlation $\eta_{AP} = f(Q, n_o)$ for each analyzed pump from the "CITY" pumping installation.



a - AP1 pump



b - AP2 pump

Fig. 3. Pumps efficiency characteristics, η_{AP}, as function of pumped flow *Q*, in the case of a direct grid power supply (at n_o rated speed)

By supplying power via the static frequency converters at various frequencies, there have been determined for various speeds n_i, the efficiencies of the pump+motor pumping systems (η_{APi}), the efficiencies of the pumping groups (*frequency converter – asynchronous motor – pump*, η_{GPi}) and the efficiency of the static frequency converter, this in function of the flows pumped towards the network.

The flows variation has been achieved by shutting down the pumps' discharge valves. The conveyed flows (corresponding to the various operating regimes) have been viewed on the SCADA software (software that surveys and controls the plant and also acquires process data) [4]. Pressures on the pumps' suction and discharge mains have been read on pressure gauges (mounted on the plant's pressure ports).

The frequency converter input electric parameters have been recorded with a FLUKE 435 power quality analyzer and all converters's output electric parameters have been read on its menu. All parameters and factors involved in this analysis have been recorded after the stabilization of operational regimes. Measurements have been carried for 4 different frequencies. Photo 4 shows the reading process, readings being carried on the frequency converter's display, for the 4 frequencies used for this study.

The measurements results have been summarized in Table 2.

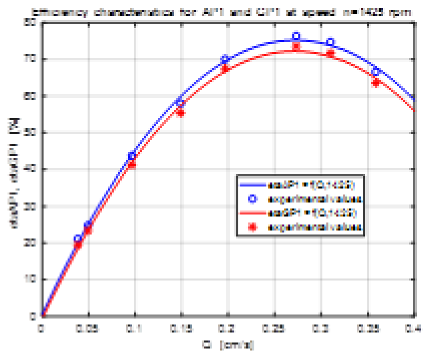
a - f = 47,5 Hz (n =1425 rpm) b - f = 45,0 Hz (n =1350 rpm) c - f = 44,2 Hz (n =1325 rpm) d - f = 40,0 Hz (n =1200 rpm)

Photo 4. Supply frequencies for the P1 pump motor

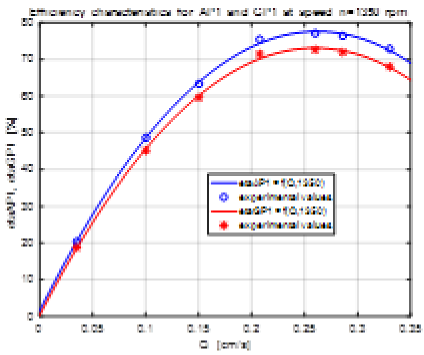
Table 2. Pumps efficiencies, η_{AP}, pumping groups efficiencies, η_{GP}, and static frequency converters efficiencies, η_{csf}, within the "CITY" installation, as a function of speed n

n (rpm)	Q (m^3/h)	H (m)	U_1 (V)	I_1 (A)	$\cos\varphi_1$ (-)	U_2 (V)	I_2 (A)	$\cos\varphi_2$ (-)	P_H (kW)	P_{E1} (kW)	P_{E2} (kW)	η_{AP} (%)	η_{GP} (%)	η_{csf} (%)
1425	1290	35,81	230	290	0,99	374	339	0,86	125,88	198,10	189	66,60	63,54	95,41
	1115	44,30	229	282	0,97	374	323	0,86	134,59	187,92	180	74,77	71,62	95,78
	985	48,70	229	274	0,97	373	309	0,86	130,72	177,93	171	76,45	73,47	96,11
	710	53,55	228	231	0,97	373	274	0,84	103,60	153,26	148	70,00	67,59	96,57
	535	54,13	229	212	0,98	372	253	0,83	78,92	142,61	136	58,03	55,29	95,28
	347	55,44	228	188	0,97	373	228	0,82	52,42	127,39	120	43,69	41,15	94,20
	178	55,84	229	174	0,97	373	207	0,82	27,09	116,05	109	24,85	23,36	94,00
	138	56,55	229	160	0,96	373	203	0,79	21,27	108,82	101	21,06	19,54	92,81
1350	1188	35,55	231	254	0,96	365	297	0,84	115,08	168,98	158	72,84	68,10	93,50
	1029	40,91	232	239	0,96	365	284	0,84	114,72	159,69	150	76,48	71,84	93,93
	937	44,11	232	232	0,96	364	275	0,84	112,62	155,01	146	77,13	72,65	94,19
	748	48,49	232	209	0,95	364	253	0,82	98,83	138,19	131	75,44	71,52	94,80
	540	51,23	232	189	0,96	363	232	0,82	75,38	126,28	119	63,35	59,69	94,23
	361	51,87	232	171	0,95	362	212	0,79	51,03	113,07	105	48,60	45,13	92,87
	126	53,03	232	145	0,96	362	188	0,76	18,21	96,88	89	20,46	18,80	91,86
1325	1136	35,23	231	241	0,96	358	286	0,84	109,06	160,33	149	73,19	68,02	92,93
	1010	39,18	231	230	0,96	358	276	0,84	107,82	153,01	143	75,40	70,47	93,46
	816	45,02	230	211	0,94	357	255	0,82	100,11	136,85	130	77,01	73,15	94,99
	599	49,10	230	187	0,94	356	231	0,81	80,14	121,29	116	69,08	66,07	95,64
	380	50,96	231	166	0,95	356	209	0,78	52,77	109,29	101	52,25	48,28	92,42
	230	51,71	231	151	0,95	355	193	0,75	32,41	99,41	89	36,42	32,60	89,53
	96	52,22	231	139	0,94	355	180	0,74	13,66	90,55	82	16,66	15,09	90,56
1200	914	31,72	231	180	0,95	323	234	0,82	78,99	118,50	108	73,14	66,66	91,14
	794	35,74	231	166	0,95	323	224	0,81	77,33	109,29	101	76,56	70,76	92,42
	625	38,89	231	149	0,95	322	208	0,79	66,23	98,09	92	71,99	67,51	93,79
	447	41,08	232	135	0,95	322	193	0,76	50,03	89,26	82	61,02	56,05	91,86
	261	42,90	231	125	0,94	321	176	0,74	30,51	81,43	72	42,37	37,47	88,42
	110	43,86	231	115	0,95	314	162	0,70	13,15	75,71	62	21,20	17,37	81,89

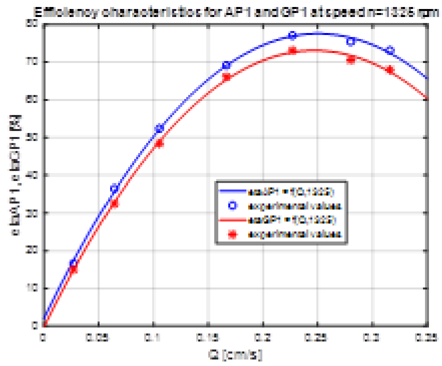
Figure 4 shows the relations $\eta_{AP1} = f(Q, n_i)$ and $\eta_{GP1} = f(Q, n_i)$ for each pumping group inside the "CITY" pumping plant.



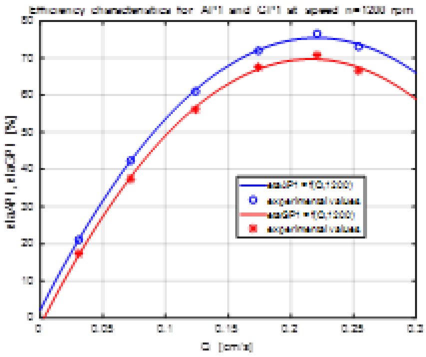
(a) - $\eta_{AP1}, \eta_{GP1} = f(Q, 1425)$



(b) - $\eta_{AP1}, \eta_{GP1} = f(Q, 1350)$



(c) - $\eta_{AP1}, \eta_{GP1} = f(Q, 1325)$



(d) - $\eta_{AP1}, \eta_{GP1} = f(Q, 1200)$

Fig. 4. Efficiency characteristics for AP1 pump (pump+motor system) and GP1 pumping group, as function of speed *n* and pumped flow *Q*, for motors driven by frequency converters

4. CONCLUSION

By reviewing Table 2, it can be seen that the efficiency of the static frequency converter depends on two parameters: the driving speed and the pumped flow. Table 3 shows the efficiencies as a function of the relative driving speed and the relative flow corresponding to each speed.

This features values covering a range between 89,53 – 96,57 % for any relative speed $n / n_o \geq 0{,}90$ and any conveyed flow. Corresponding to each speed, into the nominal point, the efficiency values shall vary between 91 – 96 %. Lower efficiency values occur when motor driving takes place at relative speeds $n / n_o < 0{,}90$ and relative flows $Q / Q_o < 0{,}30$. The efficiencies of the pump+motor pumping systems (η_{AP}) and those for the pumping groups (η_{GP}) are useful for determining the global efficiencies in pumping plants and also for the economical and power consumption features of pumping processes.

Table 3. Efficiencies of the static frequency converter (η_{csf}) as a function of the relative flow Q/Q_o, at various speeds n

Speed n (rpm)	Relative speed n/n_o (-)	Relative flow Q/Q_o (-) / Efficiency of the static frequency converter η_{csf} (%)							
1425	0,983	0,135	0,174	0,340	0,524	0,696	0,965	1,093	1,264
		92,81	94,00	94,20	95,28	96,57	96,11	95,78	95,41
1350	0,931	0,129	0,369	0,552	0,765	0,958	1,052	1,215	-
		91,86	92,87	94,23	94,80	94,19	93,93	93,50	-
1325	0,914	0,100	0,240	0,396	0,625	0,851	1,053	1,185	-
		90,56	89,53	92,42	95,64	94,99	93,46	92,93	-
1200	0,828	0,127	0,301	0,516	0,721	0,916	1,055	-	-
		81,89	88,42	91,86	93,79	92,42	91,14	-	-

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