

PAPER • OPEN ACCESS

Full-scale testing of the pump unit with a frequency converter

To cite this article: E Kan *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **883** 012112

View the [article online](#) for updates and enhancements.

Full-scale testing of the pump unit with a frequency converter

E Kan^{1*}, M Mukhammadiev², N Ikramov¹ and T Majidov¹

¹Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan

²Tashkent State Technic University named after Islam Karimov, Tashkent, Uzbekistan

Kan_E1969@mail.ru

Abstract. It is generally agreed that when using the frequency converter at pumping stations, the economic effect of its use far exceeds the losses in efficiency, and naturally, no comparison between the alternative methods of regulation is given. But, as a practice has shown at the application of the given control method, losses in efficiency can be essential. Quantitatively these losses depend on many factors (degree of regulation, type of the applied frequency converter, pumps and the driving electric motor, operating modes etc.). Therefore, for an accurate assessment of the efficiency of the control method, field tests of the unit with a frequency converter are necessary. Full-scale tests were carried out at the Teshik-Tash-1 pumping station located in the Andijan region of the Republic of Uzbekistan. The field tests consisted of determining the efficiency of the pump unit when the drive shaft speed changes. Graphical dependencies of changes in the energy parameters of the pump unit when changing the rotation frequency of the impeller shaft using a frequency converter are obtained. Tests have shown that loss values can reach significant values when using a frequency converter. If you reduce the speed of the pump impeller by 10 %, the efficiency of the electric drive (motor and converter) will also decrease by 10 %, and if you change it by 25 %, the efficiency of the electric drive may decrease by up to 40 %. The test results can be applied in the selection and feasibility study of the regulation method at irrigation pumping stations equipped with pumps of type *D*.

1. Introduction

More than 1.600 reclamation pumping stations are operated in our Republic. Irrigation pumping stations are the main consumer of electricity in the agricultural sector of the Republic of Uzbekistan. Therefore, the issues of an energy-efficient mode of their operation are important and have a priority character [1, 2]. The energy efficiency of a pumping station operation depends primarily on the selected operation mode of the pumping units. During the operation of pumping stations, it is often necessary to change the operating parameters to best cover the load schedule (primarily the pump station supply). Then you have to regulate the pumps [3, 4, 5, 6]. Most irrigation pumping stations (up to 55%) are equipped with double-entry centrifugal horizontal pumps (type "*D*"). The control methods currently used at pumping stations equipped with "*D*" type pumps can be divided into two groups: quantitative and qualitative. Among quantitative methods, the most common is the gate valve control method on the pressure pipeline (throttling) [7, 6]. The method of regulating the operating time of the pumps (switching the units on and off) is also widely used [1, 8]. Among qualitative methods, we



should mention the regulation by frequency variation of rotation of the shaft and impeller trimming (cutting) of impeller [9, 10, 11, 12, 13, 14, 15].

Since the majority of operating costs of pumping stations with electric drive motors are electricity costs, one of the effective methods of regulating pump parameters towards their reduction is to change the speed of the drive shaft of the pump (electric motor). Usually, the electric motors of pumping units operate at a fixed speed. Frequency converters allow for more complete coverage of the pumping station's water consumption schedule, which reduces unproductive water losses.

The motor speed can be changed using various devices, among which the following are common and known [4, 16]:

1. Multi-speed electric motors;
2. Use of a DC motor in which the rotor speed is controlled by a rheostat;
3. Installation as a drive for steam and gas turbines and internal combustion engines;
4. Use of hydraulic and electromagnetic couplings;
5. Application of gearboxes and belt drives;
6. Application of frequency converter.

The first five methods have significant disadvantages: difficulties in application, operation and maintenance, a narrow range of regulation, and uneconomical. These disadvantages can be avoided by using a frequency converter as a device for regulating the operation of pumping units.

A frequency converter is a device that allows a smooth start, stop, and speed control of the motor by changing the input frequency. This control method is widely used in pumping water supply stations [9, 10, 11, 12].

Irrigation pumping stations, in contrast to water supply pumping stations, do not impose strict requirements for maintaining any technological parameter. The schedule of water consumption of irrigation pumping stations is more uniform. The requirements for water consumption schedule coverage for irrigation pumping stations are also less stringent. Therefore, the economic effect of using the frequency converter in irrigation pumping stations is not so obvious. The possibility of using the frequency converter control method at irrigation pumping stations requires economic justification. For this purpose, it is necessary to find out how the technical and economic indicators change (first of all, the efficiency coefficient of the pump unit) when working with frequency converters. Therefore, the purpose of the research is to identify the nature of change in the efficiency of the pump unit when working with a frequency unit. For this purpose, field tests of a pump unit consisting of a D-type pump, an electric motor, and a frequency converter have been conducted. The object of research - pump units of Teshik-Tash-1 pumping station.

2. Methods

At the department of "Use of water energy and pumping stations" of the Tashkent Institute of Irrigation and Mechanization of Agriculture engineers are regularly carried out scientific works on increasing the efficiency, reliability of operation of hydroelectric objects [1,2,8,10,18,19,20]. Field tests have been carried out to assess the efficiency of the frequency converter. Full-scale tests were carried out at the Teshik-Tash -1 pumping station in the Jalakuduk district of the Andijan region. The pumping station takes water from the canal "Teshik-Tash" and delivers water through two steel threads of the pressure pipeline to the pressure pool. The actual capacity of the pumping station is 0.36/0.08 m³/sec. The water lifting height is 88/60 m.

The pumping station construction unit consists of:

- water intake structure;
- suction pipes;
- pumping station buildings;
- pressure pipeline;
- water outlet structure.

Pumps 200D-90 with the electric motor drive of 75 kW capacity are installed in the building of the pumping station. The table shows the main technical characteristics of the pumping station equipment.

The pump unit is equipped with the ZMK1V Series Vector Inverter 0.75 KW 380 V 3PH (ZHIMING GROUP CO., LTD). Speed stabilizing scope – 0.02%. Torque control precision – 5%.

Table 1. Technical characteristics of the main hydropower equipment of the Teshik – Tash – 1 pumping station

Main pumps	
Type	200D-90
Number of units	4
Supply of one pump	0.08m ³ / s
Electric motor	
Type	AO-291-4
Rated power	75kW
Cos φ	0.92
Voltage	380V
Rotation speed	1500rpm
Efficiency	92.5

Standard statistical methods and programs were used in the data processing. After collecting the necessary information, the frequency Converter and pump unit were tested. The purpose of the field tests was to determine the effect of changes in drive shaft frequency on power consumption. The Mastech M266 clamp meter was used to measure power consumption. This device was used to measure the current at different phases at a certain speed of the pump impeller shaft. Tong-test instrument (or Dietze Tongs) is a device whose main purpose is to measure the electric current without breaking the electrical circuit and disrupting its operation.

Procedure for conducting field tests:

1. The pump unit is started using a vacuum system. After filling the pump and the suction pipe the vacuum system is switched off and the gate valve on the pressure pipe is opened.
2. Then the speed of the impeller is changed by the frequency converter.
3. Current parameters are measured at different frequencies with the help of current measuring clamps. The limit switch is set to the position corresponding to the required measuring range of the AC. The current clamps are connected to the conductor to be measured.
4. The frequency values (in Hz) and the corresponding current values (in A) are fixed for the three phases.
5. Processing and analysis of the results obtained.

3. Results and discussions

The results of the field tests of the converter and pump unit are presented in tables 2 and 3.

Table 2. The results of field tests of the frequency converter.

№	Current frequency, Hz	Amperage (current strength), A		
		A	B	C
1	47.38	81	71	68
2	45	67	60	55
3	42	46	42	35
4	40	39	40	31
5	35	23	22	17

6	38.27	30	29	22
7	41	43	39	30
8	43	52	50	42
9	46	72	71	60
10	49.13	91	91	81
11	50	96	96	89

The motor rotor speed (rpm) and the mains current frequency (Hz) are related by the ratio

$$n = \frac{2 \cdot 60f}{p} \tag{1}$$

p is the number of poles of the motor rotor;
 f is the frequency of a current in the network (Hz).
 For an asynchronous motor

$$n = \frac{120f(1-s)}{p} \tag{2}$$

S – motor slip.

Table 3. Data processing results of field tests of the frequency converter.

Current frequency, Hz	Speed of rotation rpm	Power of the current, A.	Pow er, kW	$\frac{N_{mot}}{N_{mot}}$	$\frac{n}{n_i}$	$N_{d.loss}$ kW	η_{mech}	$\frac{\eta_{mech}}{\eta_{mech}^1}$	$\frac{(\eta_{mot}\eta_{freq})}{(\eta_{mot}^1\eta_{freq}^1)}$
47.38	1421	73.3	44	0.228	0.7	834.5	0.96	0.98	0.652
45	1350	60.7	37	0.280	0.77	1090.6	0.956	0.977	0.612
42	1260	41.0	25	0.385	0.8	1245.7	0.966	0.987	0.744
40	1200	36.7	22	0.403	0.82	1341.4	0.965	0.986	0.721
35	1050	20.7	13	0.438	0.84	1442.0	0.965	0.986	0.730
38.27	1148	27.0	16	0.508	0.86	1547.5	0.969	0.99	0.792
41	1230	37.3	23	0.649	0.9	1773.6	0.974	0.995	0.886
43	1290	48.0	29	0.719	0.92	1894.5	0.976	0.997	0.921
46	1380	67.7	41	0.771	0.95	2068.4	0.975	0.996	0.904
49.13	1474	87.7	53	0.929	0.98	2308.6	0.978	0.999	0.979
50	1500	93.7	57	1	1	2432.9	0.979	1	1.000

The three-phase circuit current capacity is determined by the following formula

$$P = P_A + P_B + P_C = \sqrt{3}IU \cos \varphi \tag{3}$$

P is power, kW;
 I is the power of the current, A;
 U is voltage, V;
 cos φ is the motor power factor.

The power of the pump varies depending on the speed of its impeller according to the laws of proportionality [4, 16, 21]:

$$\frac{N}{N_i} = \left(\frac{n}{n_i}\right)^3 \left(\frac{\eta_h}{\eta_h^i}\right) \left(\frac{\eta_v}{\eta_v^i}\right) \tag{4}$$

Taking into account that the power of the electric motor is equal to:

$$N_{mot} = \eta_u N_{shaft}$$

$$N_{shaft} = N / \eta \quad \text{or} \quad N = N_{shaft} \eta \quad \text{and} \quad N = \frac{N_{shaft}}{\eta_u} \eta \tag{5}$$

where

η_u is the efficiency of a pump unit $\eta_u = \eta \eta_{mot} \eta_{trans} \eta_{freq}$;

η is pump efficiency;

η_{mot} is motor efficiency;

η_{trans} is transmission efficiency (for a rigid or elastic coupling, it is equal to 1);

η_{freq} is converter efficiency;

N_{shaft} is shaft power;

N is pump power output;

We have

$$\frac{N_{mot} \eta \eta_u^I}{N_{mot I} \eta^I \eta_u} = \left(\frac{n}{n_1} \right)^3 \left(\frac{\eta_h}{\eta_h^I} \right) \left(\frac{\eta_v}{\eta_v^I} \right) \tag{6}$$

$$\frac{N_{mot} (\eta_{mech} \eta_h \eta_v) (\eta_{mot}^I \eta_{freq}^I)}{N_{mot I} (\eta_{mech}^I \eta_h^I \eta_v^I) (\eta_{mot} \eta_{freq})} = \left(\frac{n}{n_1} \right)^3 \left(\frac{\eta_h}{\eta_h^I} \right) \left(\frac{\eta_v}{\eta_v^I} \right) \tag{7}$$

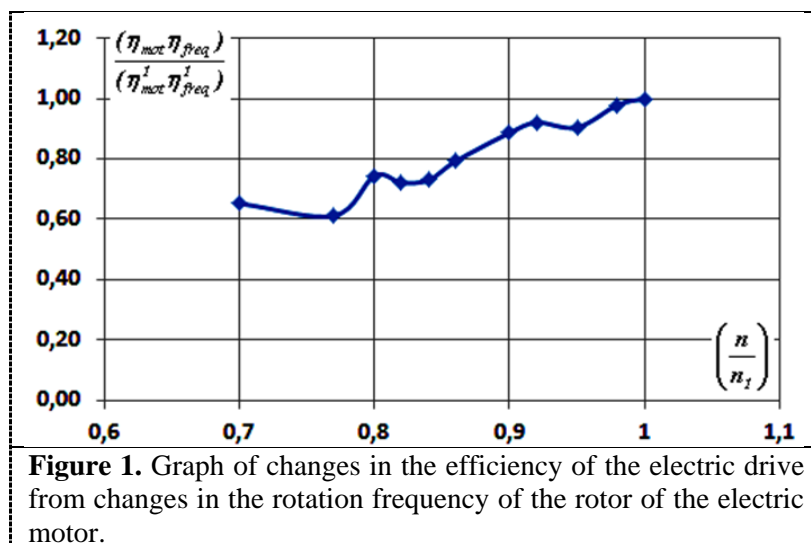
$$\frac{N_{mot} \eta_{mech} (\eta_{mot}^I \eta_{freq}^I)}{N_{mot I} \eta_{mech}^I (\eta_{mot} \eta_{freq})} = \left(\frac{n}{n_1} \right)^3 \tag{8}$$

$$\frac{N_{mot}}{N_{mot I}} = \left(\frac{n}{n_1} \right)^3 * \frac{\eta_{mech} (\eta_{mot} \eta_{freq})}{\eta_{mech}^I (\eta_{mot}^I \eta_{freq}^I)} \tag{9}$$

We will determine the mechanical efficiency approximately depending on disk losses and external mechanical losses [16]:

$$N_{d.losses} = 3,50 * 10^{-4} n^3 D_2^5 \tag{10}$$

In medium and high power centrifugal pumps, disc losses are the main type of mechanical loss. External mechanical losses depend on the size of the shaft, type of end seals, and speed. These losses are measured when the pump is "idling" (without working fluid) during balance tests.



4. Conclusions

The conducted field tests of the frequency converter operation have shown that the change of speed of a pump impeller by means of the frequency converter efficiency of the electric drive (the electric motor and the frequency converter) also varies. The reduction of speed of a pump impeller by 10 % efficiency of the electric drive also will decrease by 10 %.

Thus, saving electricity when using the frequency converter is possible only if during operation there is a need for regulation or maintenance of any technological parameter (supply or pressure). The expediency of using the frequency converter at irrigation pumping stations can be identified only by a feasibility study for the operating conditions of a particular pumping station.

References

- [1] Ergashev R Artikbekova F Jumabaeva G and Uljayev F 2019 Problems of water lifting machine systems control in the republic of Uzbekistan with new innovation technology. *E3S Web of Conferences* **97**, 05037
- [2] Khidirov S, Berdiev M, Norkulov B, Rakhimov N and Raimova I 2019 Management exploitation condition of Amu- Bukhara machine channel *E3S Web of Conferences*. **97** 05038
- [3] Sheffer F and Ufelman V 2018 Optimization of pumping equipment and its application through a comprehensive system analysis. *Jurnal "Elektricheskie stansii"* **8** pp 47-51
- [4] Lysov K I and Chayuk I A 1988 Operation of meliorative pumping stations (Agropromizdat, Moscow)
- [5] Platonov V, Tsirkunenko A and Bukhanov 2013 A Control of energy-efficient electric drive of pumping stations *IOP Conf. Series: Materials Science and Engineering* 062080
- [6] Al-Ani D and Habibi S 2013 Optimal operation of water pumping stations *WIT Transactions on Ecology and the Environment* **178** pp 185-198
- [7] Nenja V Khovansky S and Gapich A Providing of the law of pumping station parameters' regulation by means of throttling elements *Procedia Engineering* **39** pp 175-181
- [8] Ikramov N, Kan E, Mirzoev M and Majidov 2019 T Effect of parallel connection of pumping units on operating costs of pumping station *E3S Web of Conferences* **97**, 05014
- [9] Mukhamadeev E. Z. and Yagafarova Kh. N.: Frequency converter power reduction for controlling the hydraulic parameters of the pumping station. *IOP Conf. Series: Materials Science and Engineering* **560**, 012077
- [10] Kan E, Ikramov N and Muxammadiev M 2019 The change in the efficiency factor of the pumping unit with a frequency converter. *E3S Web of Conferences* **97**, 05010
- [11] Shabanov V A, Khakimov E F and Sharipova S F 2013 The analysis of the efficiency of operating pipelines main line pumps in case of the use of frequency converter in the function of the pressure regulator. *Online scientific journal «Oil and Gas Business»* **1**, pp 24–33
- [12] Vyazunov E V and Putin S V 2012 Analytical representation of characteristics of centrifugal pumps with variable rotation speed *Oil and Oil Products Pipeline Transportation: Science & Technologies* **4**, pp 67–69
- [13] Kozlov M and Chistyakov A 2001 Effectiveness of implementation systems with variable frequency drives. *J. Modern automation technologies* **1** p 76
- [14] Dresvianskii E, Pokushko M, Stupina A, Panteleev V and Yurdanova V 2018 Control of high-voltage pump motor using a frequency sine-wave filter converter. *IOP Conf. Series: Materials Science and Engineering* 450072003
- [15] Dmitriev A and Gerasimov V 2018 To the issue of energy efficiency of using frequency-controlled centrifugal pump units *MATEC Web of Conferences* **170**, 03017

- [16] Mikhailov A K and Malushenko V V 1977 Vane pumps: Theory, calculation and design *Mechanical Engineering Moscow*
- [17] Shaazizov F, Badalov A, Ergashev A and Shukurov D Studies of rational methods of water selection in water intake areas of hydroelectric power plants *E3S Web of Conferences* **97**, 05041
- [18] Shaazizov F, Uralov B, Shukurov E and Nasrulin A 2019 Development of the computerized decision-making support system for the prevention and revealing of dangerous zones of flooding. *E3S Web of Conferences* **97**, 05040
- [19] Bazarov D, Shodiev B, Norkulov B, Kurbanova U and Ashirov B Aspects of the extension of forty exploitation of bulk reservoirs for irrigation and hydropower purposes *E3S Web of Conferences* **97**, 05008
- [20] Krutov A, Bazarov D, Norkulov B, Obidov B and Nazarov B Experience of employment of computational models for water quality modeling. *E3S Web of Conferences*, vol. 97, 05008 (2019)
- [21] Bazarov D R, Vokhidov O F, Lutsenko L A, and Sultanov Sh 2019 Restrictions Applied When Solving One-Dimensional Hydrodynamic Equations *Proc. EECE 2019, Lect. Notes Civ. Eng.* **70** pp 299–305