Application of Variable Frequency Drives for Main Oil Pumping Units

Valeev Anvar¹, a), Karimov Rinat¹, b) and Kuznetsova Lyudmila², c)

¹Ufa State Petroleum Technological University
²Financial University under the Government of the Russian Federation

a)Corresponding author: anv-v@yandex.ru
b)karimov_rinat@mail.ru
c)4789mail@gmail.com

Abstract. Variable frequency drives can be used in many industries. Especially they are very promising in oil and gas industry. Variable frequency drive allows pumping in smooth regime that reduces energy consumption in comparison with multi-regime pumping. Such a drive can also increase reliability of equipment. In this Paper analysis of application of variable frequency drives in oil and gas industry is made, and method of calculation of its efficiency is presented.

1. Variable frequency drives for oil pumps

Nowadays a lot of attention is paid to the possibility of using variable frequency drives for pumps, and especially for main pumps at oil pumping stations [1].

The main advantages of the frequency control for main pumps are cost-effectiveness and smoothness of the regulation of pumping modes. Additional positive factors of application of a frequency-controlled drive are: reducing the number of switching-on. Number of shutdowns of main pumps is reduced and smooth regime of pumping is provided. It leads to a decrease of pressure waves in pipelines both in the transition from one process mode to another and reduces number of unstable process modes [2, 3, 4, 5]. Therefore, this increases: the residual resource of the main oil pipeline; reduces the risk of pipeline breaks and environmental pollution by pumping products; allows smoothly reduce the pressure at the outlets of intermediate oil pumping stations to the level of minimum pressures established by the technological parameters of the pipeline; allows eliminate throttling and partially abandon the use of interchangeable rotors at oil pumping stations.
FIGURE 1. Pumps with electric drive in oil pumping station

However, despite these advantages, application of variable frequency drives at pumping stations is ambiguous. One of the reasons for slow application of the frequency-controlled electric drive is the high cost of frequency converters, as well as the lack of a set of real criteria and methods for assessing efficiency of the frequency-controlled electric drive on the operating oil pipelines.

For many years, the main task of installing a variable frequency drive at oil pumping stations has been reducing the power consumption for pumping [6]. However, recent studies have shown that in many cases the installation of a frequency-controlled electric drive either does not result in saving electricity for pumping, or the reduction in energy consumption is so small that the payback period of frequency converters can reach several decades and their installation becomes economically inexpedient [7].

So, it is necessary to study systematic analyses of the efficiency of pumping units with variable frequency drives taking into account the prospective loading of main pipelines.

Therefore, an urgent task is the development and study of other criteria for evaluating the efficiency of using a frequency-controlled electric drive at an oil pumping station, taking into account operational factors.

FIGURE 2. Pump with variable frequency drive

2. Existing evaluation of effectiveness of variable frequency drives

In the usual method of calculating efficiency of variable frequency drives, one of the most promising criteria is reducing the cyclical loading of the pipeline [8]. Currently, the regulation of the mode of pumping oil through main pipelines is often done in steps, and it is not always possible to ensure the required daily volume of pumping at a fixed number of main pumps. In this case, the specified performance of the pipeline is ensured by the cyclic operation of the pipeline, in which the pipeline operates cyclically with a different number of switched-on pumps. At the same time, the pressures at the inlets and outlets of oil pumping stations also cyclically vary, as well as the pressures in all other sections of the pipeline, including those in dangerous sections of the pipeline, in which there are defects. Cyclic pressure change leads to an accelerated development of defects in the pipe body, which reduces the residual life and leads to the need to shorten the turnaround time as well. Therefore, the use of a frequency-controlled electric drive eliminates cyclic transfer modes or significantly reduces them and increases the turnaround time of both the linear part and the electric motors [9].

The paper presents the main results of the developed methodology for evaluating the effectiveness of the use of variable frequency drives, taking into account operational factors [8].
3. Evaluation of economic efficiency of variable frequency drives

The improved method for estimating the economic efficiency of the use of a variable frequency drive of main pumps at a pump station makes it possible to evaluate the economic efficiency (payback period) of using a variable frequency drive by simplifying the economic calculation of the cost savings of electricity, taking into account changes in the length of turnaround times of the pipeline and changes in turnaround times and service life of electric motors.

The basic method for determining the cost savings on electricity payments was developed in [3]. The developed algorithms for determining changes in the duration of the interrepair cycles of the pipeline based on data on the cyclic loading and determining the reduction in the cost of current and major repairs of electric drives at using the variable frequency drive (cost savings of current repairs) are presented below.

The method of determining the payback period is adopted by analogy with [10]:

Annual savings after the introduction of variable frequency drive \( C, \$/year \), is determined by the formula

\[
C = \Delta C_E + \Delta C_{RM} + \Delta C_{RP} - C_S
\]

where \( \Delta C_E \) - reducing the cost of paying for electricity, \$/;
\( \Delta C_{RM} \) - reducing the cost of repairs of electric motors, \$/;
\( \Delta C_{RP} \) - reducing the cost of repairing the pipeline of the technological section, \$/;
\( \Delta C_S \) - annual costs of servicing a variable frequency drive by a specialized organization, $:

\[
C_S = K_S \cdot N_{VFD} \cdot C_{VFD}
\]

where \( C_{VFD} \) - cost of the variable frequency drive, $;
\( N_{VFD} \) - the number of installed variable frequency drives;
\( K_S \) - coefficient taken on the basis of operating experience or according to manufacturers or service organizations.

In a simplified assessment, the payback period of the variable frequency drive is determined by the formula

\[
T_p = \frac{(1 + K_C) \cdot N_{VFD} \cdot C_{VFD}}{C}
\]

where \( C_{VFD} \) - cost of the variable frequency drive, $;
\( N_{VFD} \) - the number of installed variable frequency drives;
\( K_C \) - coefficient taking into account the costs of construction, installation, commissioning and other works.

The criterion for choosing the use of variable frequency drive for the pipeline system guarantee duration of their operation. The best variant of the arrangement of variable frequency drives by aggregates and oil pumping stations from the point of view of the minimum of payback period.

Maximum period of the variable frequency drive is determined 15 years.

The maximum lifetime of defects is determined by the formula, year:

\[
\frac{N_f}{N_g} = T
\]

where \( N_f \) is the annual cyclicity, cycle/year;
\( N \) - (limit number of cycles) is determined by solving the equation:

\[
H_{max} - H_0 = k_f \cdot \int_0^{N_f} V_dN
\]
where $N_{\text{max}}$ - the maximum depth of the defect; 
$H_0$ - the initial depth of the defect; 
$k_v$ - is the safety factor for the growth rate of the defect; 
$V_v$ - the growth rate of fatigue cracks.

If the reduction in the number defects to be repaired is unknown, then the reduction in the cost of repairing the pipeline is determined as follows.

The average cost of one repair when using the variable frequency drives is taken the same as when operating the main oil pipeline without using the variable frequency drives. It is obtained:

$$C_2 = \frac{C_1}{k_{CR}},$$  \hspace{2cm} (6)

where $C_1$ - the cost of repairs to eliminate defects in the work of main oil pipeline without using variable frequency drives; 
$C_2$ - the cost of repairs to eliminate defects in the work of main oil pipeline using variable frequency drives.

Then reducing the cost of repairing the pipeline between neighboring stations is equal to the cost difference $C_1$ and $C_2$

$$\Delta C = C_1 - C_2 = 3i \left(1 - \frac{1}{k_{CR}}\right)^i,$$  \hspace{2cm} (7)

Since the coefficient of reducing the cyclic loading is determined separately for each section of the pipeline between neighboring stations, the reduction of the cost of repairing the pipeline should also be determined separately for each section between neighboring stations.

Formulas (6) and (7) are obtained under the assumption that the duration of the overhaul interval is proportional to the period of safe operation, and that the development of all defects over time due to a reduction in the cyclic loading occurs evenly. The use of these formulas is possible in the absence of information about reducing the number of defects to be repaired.

Reducing the cost of repairing the pipes of the entire technological section is the sum of the decrease in the cost of repairing the pipes of each section between neighboring stations

$$\Delta C_{RP} = \sum_{i=1}^{n} \Delta C_i,$$  \hspace{2cm} (8)

where $n$ is the number of sites between neighboring stations in the technological section; 
i - is the area number between adjacent stations.

The results of the calculations is to reduce the cost of repairing the pipeline. 
Reducing the cost of repairing a pipe while eliminating defects in a pipeline is estimated either by reducing the number of defects to be repaired or by increasing the turnaround time between pipelines due to a decrease in load cycling when using a variable frequency drive.

4. Conclusion

Variable frequency drives are very promising equipment in many industries. Frequency regulation of the electric motor is effectively used in industrial enterprises, in the fields of energy, utilities and other areas. This is due to the fact that frequency regulation allows to automate production processes, to economically expend electricity and other
resources involved in production, to improve the quality of products, as well as to increase the reliability of the entire system as a whole. Frequency control can also improve the reliability and durability of the process system.

References

1. P.A. Revel-Muroz, “Ensuring energy saving in the main pipeline transport using innovative energy-saving technologies”, *Pipeline Transport-2015: Proceedings of the X International Training Conference*, Ufa, 2015, pp.181-182.
2. L.A. Zaitsev and Yasinsky G.S. *Regulation of regimes of trunk pipelines*, Moscow, Nedra, 1980, 187 p.
3. V.A. Shabanov and P.A. Revel-Muroz, “Analysis of the results of an approximate assessment of the reduction of the loading cycle when using a frequency-controlled electric drive of main pumps on the operating oil pipelines”, *Problems of collection, preparation and transportation of oil and oil products*, 2016, Vol. № 1 (103), pp. 64-75.
4. V.A. Shabanov and P.A. Revel-Muroz, “Methods of multi-criteria evaluation of the effectiveness of the use of VFD at the facilities of main oil pipelines”, *Transport and storage of petroleum products and hydrocarbons*, 2016, Vol. 2, pp. 11-17.
5. I. Scherban, K.A. Borisov, E.M. and Abiyartdinov, “On the development of technology for the transport of petroleum products based on the speed control of pumping pumping units”, *Transport and storage of petroleum products and hydrocarbons*, 2007, Vol. 6., pp. 7-10.
6. AG. Gumerov, K.A. Borisov, A.Yu. Kozlovsky, “The introduction of energy-saving technologies in pipeline transportation of oil and petroleum products”, *Oil industry*, 2007, Vol. 3, pp. 85-88.
7. S.K. Evlakhov, “*Methodical prerequisites for the study of optimal flow control problems in the network of trunk pipelines*”, Oil, gas and business, 2007, Vol. 1-2, pp. 28-30.
8. V.A. Shabanov and P.A. Revel-Muroz, “Methods of multi-criteria evaluation of the effectiveness of the use of VFD at the facilities of main oil pipelines”, *Transport and storage of petroleum products and hydrocarbons*, 2016, Vol. 2, pp. 11-17.
9. P.A. Revel-Muroz, “On the issue of estimating the increase in the interval between repairs of the pipeline when using the VFD”, *Science and technologies of pipeline transportation of oil and petroleum products*, 2016, Vol. 3 (23), pp. 37-40.
10. RD-29.160.30-KTH-267-10 *The method of substantiating the use of devices for controlling the starting current of high-voltage motors of pumping units*, Moscow, JSC “Transneft”, 2010, 149 p.