Algorithm for Estimation of Electricity Consumption Reduction by Using Variable Frequency Drive of Main Line Pumps (February 2016)

V. A. Shabanov, E. F. Khakimov,
Ufa State Petroleum Technological University – Automation Department,
Kosmonavtov Str. 1, 450062, Ufa, Russia
E-mail: shabanovva1@ya.ru

***Abstract*—The article is about using of variable frequency drives for reduction oil pumping main line pumps energy consumption. Block diagram of developed computer program is shown in the article. The computer program allows to determine the reduction of energy consumption and to estimate payback period of variable frequency drives.**

***Keywords:* main line pump, oil pipeline, variable frequency drive, efficiency, oil pumping station.**

I. Introduction

Nowadays main line pumps are connected in series for purpose of oil pumping. In this process dozens of pumps are used on a process section, consisted of a number of oil pumping stations (OPS), in “from pump to pump” mode. Number of working pumps depends on a required pipeline capacity. Regulation of the pipeline capacity by means of changing of number of working on a process section pumps or their parameters are main methods of operating modes regulation. [1][2]. However, using this method implies that pipeline capacity may differs from rated pumps capacity. Thus in this case main line pumps will have efficiency less than rated. When required capacity cannot be achieved by changing of working pumps number, method of cyclic pumping and pressure reducing valves (PRV) are used. Changing of working pumps number and using of PRV implies additional power losses and ineffective energy using [3][4]. That is why using of variable frequency drives (VFD) on main line pumps is possible solution for reduction of OPS energy consumption [5][6]. The objective of this article is to estimate reduction of power consumption for oil pumping by means of using VFD.

II. Object Analysis

The main documents for operated oil pipeline are: technological modes map and modes compliance information. Technological modes map contains all pipeline operation modes that can be established. Modes compliance information contains information about used in fact modes and used modes measured parameters.

Evaluation of pumps energy consumption changing in case of using VFD is very important for estimation of advantages VFD of pipeline pumps. One of the biggest problems in this issue is processing of bulky database. This problem is also vital for other IT sections [7][8].

In case of using VFD with main line pumps reduction of energy consumption is achieved by two main reasons: elimination of power losses in PRV and increasing of pumps efficiency by means of speed reduction in modes with low pipeline capacity [9][10].

Power losses in the valves ΔP_{PRV} are in direct ratio with the pressure decreasing in the valves Δp_{PRV} when PRV are being used

$$\Delta P_{PRV} = \Delta p_{PRV} \cdot \mathrm{Q_p}, \quad (1)$$

where . $\Delta p_{PRV} = p_m - p_o$ (2)

p_m - pressure in the OPS manifold, N/m2.

p_o - OPS output pressure, N/m2

Qp – pipeline capacity, m3/s;

If VFD are being used, than there is no need of PRV using, because pressure decreasing is achieved by decreasing of rotation speed. Thus energy consumption is reduced by a value of losses in PRV.

In modes with low capacity efficiency of rotating with rated speed pumps is lower compare to efficiency of rotating with lower than rated speed pumps. Thus in such modes consumed by pump with decreased by VFD rotation speed power is lower than consumed by unregulated pump power.

$$\Delta P_{eff} = p_{dif} \cdot \mathrm{Q_p} \cdot \left(\frac{1}{\eta_{unr}} - \frac{1}{\eta_r} \right), \quad (3)$$

Where p_{dif} – differential pressure that equates difference between pump output pressure p_o and pump input pressure p_i, N/m2

$$p_{dif} = p_o - p_i; \quad (4)$$

η_{unr} – efficiency of rotating with rated speed pump; η_r - efficiency of rotating with lower than rated speed pump.

Efficiency of rotating with lower than rated speed pump can be calculated using equation [4]

$$\eta_r = \eta_{rtd} - (q - \nu)^2 \cdot \eta_{rtd} / \nu^2, \quad (5)$$

where η_{rtd} – rated efficiency; q = Q/Q_{rtd} – relative value of pump capacity; Q and Q_{rtd} – actual and rated capacities of pumps as following; $\nu = \omega/\omega_{rtd}$ - relative value of pump rotation speed; ω and ω_{rtd}– actual and rated rotation speed of pumps as following.

In case of using VFD instead of RPV reduction of power losses equates power losses in (1) and (3) in total.

$$\Delta P_{VFD} = \Delta P_{PRV} + \Delta P_{eff}. \quad (6)$$

The problem of using equations (1) - (6) for operating pipeline is necessity of using input data from technological modes map and modes compliance information. Technological modes map and modes compliance information consist of millions of numerical parameters about operating modes for a year. That is why for purpose of automatically calculations of energy consumption computer program must have algorithm of searching and picking information from different databases on every step of calculations. Main steps for performing calculations based on designed algorithm are shown on Fig. 1

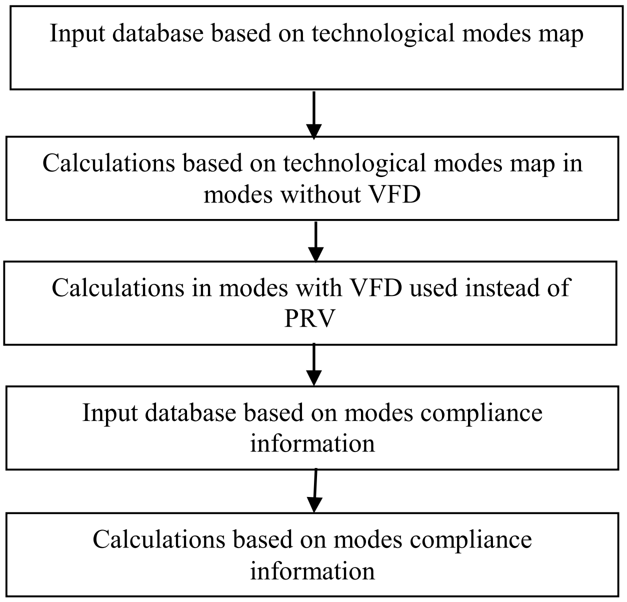

Fig. 1. Algorithm of calculation of energy consumption on an operating pipeline pumps

III. CALCULATIONS

Developed program for evaluating of energy consumption reduction in case of using VFD instead of PRV consist of following steps:

1. Creation database based on technological modes map and equipment information

1.1. Making «technological modes map» database. Part of this database is shown in table 1.

In the first column of the technological modes map number 001 means that there is only one main line pump working on the whole process section. The second column contains information about pipeline capacity per year, day, and two hours. For every OPS there is information about input, output, and manifold pressure, type (NM10000x210) and quantity (1) of using pumps. 1ch+№2(3) is pumps working mode. 1ch means that there is 1 working charging pump on the first OPS, №2(3) means that main line pump number 2 or 3 can be in work on the first OPS.

1.2 Equipment database creation that contains rated parameters and head-capacity curves coefficients for every pump

2. Calculations based on technological modes map in modes without VFD

2.1. Working database (WDB) is formed for calculations.

2.2. Head calculations for every pump

$$H = \Delta p_{dif} / (\rho \cdot g), \quad (7)$$

where g- gravity acceleration;

ρ – pumped oil density.

2.3. Efficiency for every main pipe pumps and charging pumps is calculated (ν=1 as pump are unregulated) by using (5). Q_{rtd} for every pump is taken from equipment database depending on pump number.

2.4. Calculation of power consumption for every electric drive. For these calculations electric drive efficiency, electric drive utilization factor $k_{u.f.}$, and electric drive load power $P_{u.f.}$ should be calculated.

2.5. Total amount of power consumption by all pumps P_Σ and specific energy consumption (energy consumption per hour, kW*h divided by pipeline capacity, t/h) are calculated.

$$W_S = \frac{P_\Sigma}{Q}. \quad (8)$$

An example of energy consumption calculations in modes without VFD is shown in Table 2

3. Calculations of same modes but in case of using VFD instead of PRV. Needed information is taken from calculations based on technological modes map in modes without VFD.

3.1. Calculation of power losses and head losses in PRV.

$$\Delta H_{PRV} = \Delta p_{PRV} / (\rho \cdot g). \quad (9)$$

3.2. Calculation of needed for elimination of the PRV head losses relative rotation speed of the main line pump,

$$\nu = \sqrt{1 - \frac{\Delta H_{PRV}}{a}}. \quad (10)$$

3.3. Using (5) pump efficiency in case of using VFD is calculated

3.4. Head produced in case of using VFD is calculated using equation

$$H = a \cdot \nu^2 - b \cdot Q^2. \quad (11)$$

In (10) and (11) a and b are coefficients of head-capacity curve

3.5. Power that consumed by regulated drives (with VFD) is calculated. Efficiency of the frequency transformer is taken into account

TABLE 1
PART OF «TECHNOLOGICAL MODES MAP» DATABASE FOR ONE OF THE MODES

Oil viscosity n = 14,43802 mm^2/s, oil density ρ = 865,4 kg/m^3								Specific energy consumption
Mode №	**Capacity**	**Parameter name**	**OPS1**	**OPS2**	**OPS3**	**OPS4**	**OPS5**	
1	2	3	4	5	6	7	8	9
	t/2h							kW·h/t
001	7891,67	Type and quantity of pumps	NM10000x210; 1	-	-	-	-	1,58
		Pumps working mode	1ch+№2(3)	-	-	-	-	
		P_i, kg/sm^2	9,2	11,3	9,9	11,5	1,0	
		P_m, kg/sm^2	33,7	11,3	9,9	11,5	1,0	
		P_o, kg/sm^2	26,0	11,3	9,9	11,5	1,0	
		Power, kW	6225					

TABLE 2
AN EXAMPLE OF ENERGY CONSUMPTION CALCULATIONS IN MODES WITHOUT VFD

Mode	**Head using (7), m**	**Pump efficiency (5)**	**Pump input power, kW**	**Drive utilization factor**	**Drive input power, kW**	**Power losses in PRV, kW**	**Power consumption total amount P_Σ, kW**	**specific energy consumption kW*h/(t/h)**
004	233,7	0,88	5731,5	0,90	5878,4	1512,9	26282,7	3,33
001	282,8	0,63	4634,9	0,56	4519,4	1101,4	5937,1	1,50

TABLE 3
AN EXAMPLE OF POWER CONSUMPTION CALCULATIONS IN CASE OF USING VFD

Mode	**Q , (t/2h)**	**Δp_{PRV}, kg/sm^2**	**ΔH_{PRV}= $\Delta P_{PRV}/(g*p)$, m**	**Pump rotation speed, ν**	**∑P, kW**	**Specific power W_S, kW*h/(t/h)**
004	15750,00	5,3	61,1	0,87	24827,5	3,15
001	7891,67	7,7	88,89	0,81	3746,0	0,94

TABLE 4
MODES COMPLIANCE INFORMATION DATABASE

Date	**Operational mode**		**Working time, h**		**Capacity, t*1000/day.**	
	On a plan	**In fact**	**On a plan**	**In fact**	**On a plan**	**In fact**
12.01	001	001	10	10	37,9	38,6
13.01	002	002	5	5	33,5	32,9
17.01	004	001	18	18	141,8	142

TABLE 5
PART OF ENERGY CONSUMPTION REDUCING CALCULATIONS

Date	**Operating modes**	**ΔWs, kW*h/(t/h)**	**Q. t/2h**	**Working time, t, h**	**Reducing of energy consumption for the time t. ΔW, kW*h**	**Reducing of electricity cost for the time t, rubles*1000 / dollars**
01.01.2011	004	0,185	15750,00	7	10186,6	30,6/ 383
01.01.2011	001	0	10666,67	17	0	0
…	…	…	…	…	…	…
12.01.2011	001	0,564	7891,67	10	22244,3	66,7/834
…	…	…	…	…	…	…
Total for the month					298000,0	893,0/11163
…	…	…	…	…	…	…
Total for the year						7900,0/98750

3.6 Power that consumed by all left drives (without VFD) is calculated.

3.7 Total amount of power consumed by all regulated and all unregulated pumps is calculated.

3.8 Specific energy consumption (Power consumption by all pumps divided by pipeline capacity) is calculated.

Part of the power consumption calculation in case of using VFD instead of PRV on the first OPS for modes shown in Table 2 is shown in Table 3.

As can be seen, when comparing table 2 and 3, in mode №

004 specific power decreased by 0,18 kW*h/(t/h) (5%) by using VFD instead of PRV. In mode № 001 specific power decreased by 0,56 kW*h/(t/h) (37%) by using VFD instead of PRV

3.9 Difference between specific power in case of using PRV and specific power in case of using VFD ΔWs, kW*h/(t/h) is calculated.

This difference is reducing in power consumption by means of using VFD.

4 Creation of database based on modes compliance information for the chosen pipeline. Part of the database is shown in table 4.

5 Calculations based on modes compliance information.

5.1 Needed information for every used in fact mode is taken from previous databases

5.2 Decrease of power consumption by using VFD instead of PRV is calculated for every used mode for a month or year.

5.3. Total reducing of power consumption for the whole chosen period is calculated

5.4. Total reducing of electricity cost and payback period are calculated.

Part of total reducing of electricity cost and payback period calculations is shown in table 5. Taken price of 1 kW*h is 3 rubles (3,75 cents).

Calculations based on chosen process section showed that in case of low pipeline load (from 0,65 to 0,75 of rated) elimination of PRV using by means of VFD can reduce electricity costs by 8 million rubles (100 000 dollars) . In this case payback period would be 6,3 years (taken VFD cost is 50 Million rubles (625 000 dollars). If pipeline load is higher than 0,75, than payback period would be more than 20 years).

IV. CONCLUSION

1 Algorithm of calculation of main line pump power consumption reduction in case of using VFD in case of using PRV on oil pumping process section was developed.

2 Calculations showed that reducing of energy consumption and payback time for VFD depends on operating mode. Calculations based on chosen process section showed that in case of low pipeline load elimination of PRV using by means of VFD can reduce electricity costs by 8 million rubles (100 000 dollars). In this case payback period would be 6,3 years

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