Development of an algorithm for determining the optimal start time of oil wells to reduce the peak load

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Abstract. The subject of this work is the development of an algorithm for determining the start time of wells in the automatic re-activation mode to save power during peak hours. This measure is relevant for the consumer and for the energy-supplying organizations, because the redistribution of load on peak hours or night zones will provide the most economically balanced operation of the enterprise, and will allow the most efficient use of sources of electrical energy supply organization. The algorithm development will provide operational control and management of the operating mode of the considered equipment in automatic mode. Besides, this will reduce the influence of the human factor on the operation of these consumers and minimize deviations in the hourly planning of electricity consumption, as well as reduce the cost of paying for consumed power. The short-term prospect of implementing this development will ensure optimal power consumption of the periodic well stock during peak load hours, and, consequently, will provide savings in the material resources of the enterprise.

1. Introduction

According to the dynamics of oil production, there are 4 stages of oil field development. The first stage is the development of the facility, the second is permanent production, the third is a decrease in oil production, and the fourth is the final stage.

In the oil and gas production department considered in this paper, there are already fields that are at the 3rd and 4th stages of development, which are characterized by a high degree of waterlogging of wells. Some of the wells have insufficient flow rate (inflow) due to the physical properties of the reservoir. In this regard, measures are being developed to switch wells to the automatic re-activation mode (hereinafter-ARM) to maintain the dynamic liquid level and save electrical energy.

Since 2014, every year there has been an increase in wells operating in the ARM mode (figure 1). From the analysis of this well stock, it was revealed that today there are 627 electric submersible installations (hereinafter referred to as ESI) operating in a periodic mode.
The company pays for the actual electrical energy consumed and the purchased (consumed) power. The volume of purchased (consumed) power is defined as the average monthly consumption of the enterprise during peak hours, during which the maximum aggregate consumption was observed for the subject of the Russian Federation in which the enterprise is located.

Peak load hours are the time interval of the day when the load on the power supply network and generating equipment are the highest [1-3].

However, the start and the duration of time intervals for planned peak hours may change each month depending on the length of daylight, total load, and other factors. Statistics show that the time interval of the maximum hours of the same month does not change significantly each year.

Power is fixed in the power system during the billing hours, which are determined only on business days of the month at the time of peak electricity consumption in the region of the Russian Federation. At the same time, the consumer does not have information about what exact hour will be calculated, so it is not known when it is necessary to reduce consumption.

Every year, statistics are made on the time intervals during which the load in the power system is maximum. The maximum consumption range in winter is from 3 to 5 hours a day, in summer—from 6 to 12. That is why it is necessary to reduce the power not at a certain hour that falls during peak hours, but throughout the entire time interval that falls during peak hours.

Reducing electricity consumption during the billing hour will reduce power costs.

2. Materials and methods
The algorithm presented in this paper was implemented in a program created in the Microsoft Office Excel office Suite.

The analysis of the operating mode and consumption of electricity and capacity was carried out based on the data obtained from the automated power management system, the software tool «unified system for working with the well Fund», the information system «portal technologist», the oilfield complex «Alfa» and other sources.

3. Analysis of well operation mode
When analyzing the consumption system of an oil company, consumers were identified who have a re-short-term operation mode, namely wells with a set periodic operation mode (ARM) [4-8]. In this case, wells are operated with periodic stops of ESI operation for liquid accumulation.

According to electric power engineering, these wells are individual receivers of electric energy with a cyclic nature of the load schedule (figure 2), which is described by the formula:

![Figure 1. Analysis of changes in the stock of wells operating in the ARM](image-url)
\[ t_{\text{cycle}} = t_{\text{idle}} + t_{\text{work}} = \text{const}, \]  

where \( t_{\text{idle}} \) – idle time; \( t_{\text{work}} \) – work time; \( t_{\text{cycle}} \) – cycle time.

To date, the time when wells are put into operation is not regulated, and the well is started if there is a request to change the mode of operation of the well.

According to optimizing electricity and capacity consumption in the context of the daily schedule, it is necessary to optimize the start-up time of installations so that the idle hours of wells fall on peak load hours.

![Figure 2. The mode of operation](image)

If it is not possible to completely match the idle hours with the maximum load hours, the task must be reduced to a minimum match between the working hours and the maximum consumption period.

4. **Optimization of the operating mode based on the algorithm**

To solve this problem, an algorithm was developed to determine the optimal start-up time of the well [9-10]. The principle of operation of the proposed algorithm is based on the search for the optimal start-up time depending on the time of receipt of the request to change the operation mode of the well.

To implement the launch time determination, you must perform the following operations:

1. Select the main parameters for calculation (operating time, downtime, and acceptable well stop time).
2. Determine the current date.
   2.1. If the current date is the last working day of the month or a weekend or holiday, which may be followed by an interval of non-working days and not followed by working days of the current month, then calculation should be made for the first working day of the following month.
3. Determine the max hours and their duration.
4. Select the ESI involved in the calculation:
   3.1. If the work cycle of wells is less than or equal to 1 (short-term operation), they are not used in the calculation.
   3.2. If the daily cycle of the ESI is not a multiple of 24 hours (+/- 2 hours), then the possibility of adjusting the mode is considered, provided that the daily volume of oil production is maintained; otherwise, the installations are not used in the calculation.
   3.3. The wells are divided into 2 groups:
      – the first group of wells with the downtime from 4.5 to 10 hours a day;
      – the second group – wells with the downtime of more than 10 hours per day.
5. The start of cycle:
   4.1. If the initial startup time (the time of a request receipt for changing the operation mode) is before the interval of max hours, then the reference point is assumed to be equal to the interval end of max hours, we plot from it the maximum number of periods of the well (\( N \)). We obtain the time of...
start. Otherwise, the reference point must be assumed to be equal to the end of the max interval of the next day (i.e. +24 hours). The calculation is made from the next day to the current day.

4.2. If the downtime period of the well exceeds the interval of max hours, start the well at any time, provided that the well will not operate during max hours.

5. Determine the optimal well start time and display it on the screen.

6. Provide the opportunity to start the well at the optimal time.

7. Shift to the next month:

7.1. Five days before the end of the month, an alert is generated, which offers the possibility of recalculating the start time of wells for the next month. The responsible specialist confirms/does not confirm the restart of wells. If there is a confirmation of the restart, the system sends a command to complete the well cycle on the last day of the month (the first working day of the next month), and the start time is calculated. A command is given to automatically turn on the well at the specified time. If the restart is not confirmed, the well does not change its operating mode.

7.2. The calculation are made relative to the ESI of clause 3.3:

– for the first group of wells in the calculation period, if there is one forecast interval of maximum hours with a total duration of no more than 6 hours per day (applicable for 7 months of the year);

– for the second group of wells, applicable during the year.

7.3. The possibility of switching should be checked every month based on the conditions of section 7.2.

Well start-up is performed remotely in the software tool "remote control and operational control of objects". To assess the practical applicability of the proposed algorithm, it was implemented in a program created in the Microsoft Office Excel office Suite. The main window of the developed program is shown in figure 3 and is a simple interface with data entry cells, where the user needs to independently set the operating time, downtime, and select peak hours.

On the panel, there is a button «Determine the launch time», pressing which activates the algorithm, and the optimal start time of the well appears in the start time output cell. Clicking the «Clear» button deletes the data entered by the user. The prototype showed that the algorithm was correct.

Since the main task of this work is to develop an algorithm and not software, the following assumptions were introduced to simplify the calculation at the design stage:

1) we consider options for working wells only with integer values of hours of operation and downtime;

2) the start time of the well is rounded to an integer (minutes are not taken into account).

| Enter the working time | 2 |
|------------------------|---|
| Enter the idle time    | 4 |
| Select peak hours      |
| 0 1 2 3 4 5 6 7 8 9 10 11 |
| 12 13 14 15 16 17 18 19 20 21 22 23 |
| Start time             | 1 hour |

**Figure 3. Main application window**

5. **Calculation of economic efficiency**
The cost-effectiveness calculation was performed for November, since the range of planned maximum load hours in this month is the most averaged. After downloading the data from the "unified system for working with the well Fund" software, it was found that 627 wells in the ARM mode were involved in the work for this period.
However, the launch time was determined for only 456 of them. The rest of the wells (171 units) were not included in the calculation for the following reasons:

1) 72 wells have a working period of no more than 1 hour. It is not advisable to consider this option since these wells will work every hour;
2) 82 wells have non-integer values of operating hours and downtime;
3) 17 wells have a period value that is not an integer divisor of the number 24;

The quantitative components of the selected wells are clearly shown in the diagram shown in figure 4.

![Figure 4. Quantitative components of selected wells](image)

After determining the optimal time for putting wells into operation, a well start-up schedule is created as an example. As mentioned above, the start time of the wells is rounded off. Scheduled peak hours in November are 4 pm, 5 pm, and 6 pm.

Having constructed daily graphs of power consumption (figure 5) at the start time of wells before the adjustment and at the found optimal start-up time, the power consumption during peak loads were analyzed [11-15].

![Figure 5. The daily schedule of power consumption before and after adjusting the start time of wells](image)
At the same time, the graphs in figure 5 show that the maximum power consumption in the power system is significantly reduced. Based on the above, it was found that the implementation of this measure can bring economic benefits by reducing the cost of active capacity. The purchasing capacity is determined during the hours when the maximum power is consumed not by the enterprise, but by the entire region. To calculate the amount of power consumed, you need to know the estimated hours when the power consumption is recorded. During the calculations, the annual economic efficiency of the enterprise will be 26 million rubles.

6. Conclusion
The increase in the number of wells being converted to ARM mode requires solving the problem of optimizing their start-up to reduce power costs by distributing the load on the hours of semi-peak or night zones.

To solve this problem, an algorithm was developed for determining the optimal start-up time of the well. The practical applicability of the algorithm was evaluated in a program created in the Microsoft Office Excel office Suite (as a prototype).

It is planned to implement regulation of the operation mode of this group of electric receivers and launch an automatic generation of reporting forms, which will be used to control wells and thus minimize deviations in hourly planning of electricity consumption and reduce the cost of paying for power consumption.

Thus, by modernizing the existing system of consumption, the company can save a large amount of its budget. It should be noted that this algorithm can be applied to any electric receiver that has a periodic operation mode and meets the above requirements.

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