Electrotechnical complex for autonomous power supply of oil leakage detection systems and stop valves drive control systems for pipelines in arctic region

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Abstract. The article is dedicated to the important task of detection and elimination of liquid hydrocarbon leak in oil pipelines. The technological, regulatory and geographical aspects of the use of existing oil leakage detection systems (LDSs) and pipeline stop valves drive control systems are considered. The authors have proposed a new solution for autonomous power supply of oil LDS and stop valve drive control systems for pipelines located in inaccessible areas. The proposed autonomous power supply complex is based on thermoelectric generation units. The composition and parametric sufficiency of the autonomous complex is substantiated. The authors have developed the laboratory test bench, which verified the technical characteristics of the complex. The authors have substantiated the possibility of various designs for application of such complexes in existing pipelines.

1. Introduction

Total length of pipelines in Russia is approximately 70,000 km for oil trunk pipelines, and more than 400,000 km for field pipelines [1]. Development of new oil fields requires the development of an oil transportation system, and as a result the range of pipelines increases annually. Recently oil companies started developing the Arctic zone, which is one of the most difficult zones for operation [2]. By estimation of experts in this field, in 2050 Arctic shelf will provide from 20% to 30% of total oil production [3].

Constant wear of pipelines leads to emergency situations, such as pipeline leaks and oil spillages. Resulting ecological consequences are hard to calculate because oil pollution affects various natural processes and interrelations, changing live environment for many living organisms [4]. Even a relatively small leak could produce a devastating effect on the environment, especially when oil gets into a hydrologic system.

In accordance with statistics for oil fields in Western Siberia, 92% of all leakages in field pipelines are caused by internal corrosion of the pipeline, 3% of cases are caused by external corrosion of the pipeline, 2.7% of cases are caused by violation of service regulations and 1.4% of cases are caused by constructional defects [5]. Metal corrosion is the cause of leakages in oil trunks in 90% of cases. A quantity of oil lost due to pipeline leaks in 2018 is 54,900 metric tons, which is approximately equal to 1% of oil production during that year, as shown in Table 1 [6].
Table 1. Information about oil leakages from pipelines in 2018 in Russia

| Object              | Total number of oil leakages, cases | Number of oil leakages caused by corrosion, cases / % | Oil lost from pipeline, metric tons |
|---------------------|-------------------------------------|-----------------------------------------------------|------------------------------------|
| Oil company         | 7 771                               | 7 017 / 90%                                        | 53 151                             |
| Other producers     | 355                                 | 310 / 87%                                          | 1 770                              |
| Total in Russia     | 8 126                               | 7 327 / 90%                                        | 54 921                             |

2. **Power supply of LDS**

Securing safe and reliable operation of pipelines, especially in the Arctic region, is a high-priority task. As a solution, various leakage detection systems (LDS) such as constant control (hydraulic leakage location, flow comparison, flow change rate comparison, acoustic emission and others) or periodical control (differential pressure control, probe, radioactive, acoustic methods) systems are used [7, 8, 9]. The main purpose of LDS is the detection of leakage occurrence and determination of the oil leakage location. In order to estimate the extent of leakage and the location, the system uses sensing devices to measure static and dynamic pressure and pipe flow.

In order to reduce possible damage caused by oil leakages from trunk pipelines, stop valves are used. Gate, wedge or ball valves are used for shutting down lineal parts of oil trunk pipelines in cases of leakages [10]. Installation of stop valves is mandatory at endpoints of pipelines’ parts, which are passing through natural and artificial obstacles, natural areas of preferential protection, and locations of higher corrosion danger [11]. In order to provide an automated or remote control of the stop valve, a pneumatic, hydraulic and electric drives with the corresponding control systems are used.

The location of oil pipelines in remote and hard-to-reach places complicates the establishing reliable electric power supply of LDS, which consist of register and auxiliary devices (middle level), sensing devices (low level) and stop valves drive control systems, as it can be seen in Figure 1. The total average power of electrical consumers in the data collection and control point does not exceed 30 W.

The existing methods of providing an electrical power supply for the data collection and control point of LDS and for the stop valve control are:

- power transmission lines 0.4/6/10/35/110 kV from centralized energy system;
- power transmission lines 0.4/6/10 kV from local energy sources (diesel generators, gas turbines) [12];
- autonomous energy complexes with renewable energy sources (wind generators, photovoltaic

![Figure 1. The elements oil LDS and stop valve control.](image-url)
cells) [13].

In a case where underground cable or overhead power transmission lines run along the pipeline, there is no difficulties with power supply of low and middle levels of data collection and control point for the oil LDS and the stop valve control. However a construction of the power transmission line along the pipeline requires high investment expenditures.

The usage of autonomous complexes based on wind generators is limited by several factors: a lack of required wind potential in the area; the limited operation of moving parts (both windwheel and rotor) at extremely low temperatures (lower than 50°C); the snow load, especially at temperatures close to 0°C; the significant inequality of power generation, which requires compensation by means of energy storage devices of higher capacity [14].

The application of autonomous complexes, based on photovoltaic cells is limited by the several factors like an occurrence of polar nights in arctic regions and snow loads, especially at temperatures close to 0°C.

As all aforementioned methods of electric power supply have shortcoming limiting their application for supply of pipeline oil LDS and stop valve control data collection and control points, new solution for the problem of power supply is required.

3. Autonomous power by thermoelectric generators

As a solution to this problem authors developed the electrotechnical complex for autonomous power supply of oil leakage detection systems and stop valves drive control systems, which uses units of thermoelectric generators (UTEG). This complex is autonomous, blast and fire proof, requires low-maintenance (once per year) and has a long service life (not less than 10 years).

In order to ensure the effective operation of UTEG it is required to have the maximum permissible temperature difference between sides of module, providing the constant heat (Qh) on one side and effective dissipation of the heat energy (Qc) on another side. Produced electric power is directly proportional to a square of temperature difference ($\Delta T$): $P = (Qh – Qc) \sim \Delta T^2$.

Up to the present time a substantial limiting factor for thermoelectric generators application is a relatively low efficiency of heat flow to electric energy conversion – from 3% to 8%. However for cases of relatively low loads, where it is impossible or economically inadvisable to construct power transmission lines from centralized or local energy sources, thermoelectric generators (UTEG) could be irreplaceable.

Installation of the UTEGs on a pipeline with temperature above 40°C, allows achieving temperature difference between hot and cold sides of the module required for generation of electric energy [15]. The UTEG is most effective during winters when environmental temperature could reach minus 40–60°C. An evident limitation in application of UTEG as an energy source is the difficulties in obtaining required temperature difference during summer, especially in the continental climate.

It is possible to describe several types of implementation for the autonomous power supply complex based on UTEGs depending on a geographical location represented in Figure 2:

- 1st type (passive air heatsink) – for inland oil pipelines in northern climate zones;
- 2nd type (heatsink with phase transition technology) – for underground oil pipelines and pipelines in continental climate zones;
- 3rd type (passive water heatsink) – for underwater segments of oil pipelines.

For the 1st and 2nd types of implementation, a significantly increased number of thermoelectric generators in one complex could be required due to the reduced effectiveness of UTEG cooling during summer. This problem can be solved by means of the additional energy source – photovoltaic panel (PV). Effectiveness of each energy source will be significantly reduced in different seasons (UTEG in summer, PV in winter) allowing alleviation of the multirelated drawbacks [16].

Under quiescent conditions the electric energy is stored in the emergency energy source. As an emergency energy source LiFePO4 or Li4Ti5O12 accumulators can be used. A controller provides optimization of the energy consumption and the maintenance charge of accumulators. This ensures flexibility of the system as well as direct relation between the investment expenditures, the necessity
of periodical updates and specific operation conditions for the data collection and control point [17, 18].

Figure 2. Environmental zones for UTEG implementation types.

In order to analyse operating modes of UTEG in autonomous power supply complex, the imitational laboratory test bench represented in Figure 3 was developed. The test bench consists of: (1) tank for heating of liquid; (2) temperature relay for assignment of liquid heating temperature; (3) circulating pump; (4) model of pipeline wall; (5) UTEG; (6) passive air cooling radiator; (7) temperature control unit for hot and cold sides of UTEG; (8) power load; current (9) and voltage (10) meters.

Figure 3. Photo of a laboratory test bench with UTEG.

Energy characteristics of the UTEG module (TGM-127-1.0-0.8) were obtained experimentally for the load resistance equal to resistance of the internal resistance of the module (approximately 15.3 Ohm) and are represented in Figure 4.
Application of autonomous power complex with the UTEG (2nd type) in arctic zone for electric energy supply of data collection and control point for oil pipeline LDS and stop valves drive (with oil temperature 40°C) requires installation of 200 UTEGs and total surface of 0.5 m². In order to ensure the reliable power supply by complex with the UTEG in subarctic zone, installation of PV modules with rated power 50–100 W is advised.

4. Conclusion
An implementation of the developed power complex not only solves the problem of energy efficient power supply of oil pipeline leakage detection systems and stop valves drive control systems, but also allows installation of the system in remote and hard-to-get places, especially in arctic regions, reduces time required to locate and stop the leakage by shutting down the oil flow by valves. As a result the negative impact on the environment and financial expenses required for accident elimination can be significantly reduced.

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