Remote area power supply system for oil leakage detection systems and stop valves drives for pipelines

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Abstract. This paper describes problem of electrical power supply of data collection points for leakage detection and stop valve control systems, designed for emergency shutoff of fault parts of oil pipelines in areas without centralized power supply. Autonomous electrical power supply complex, based on thermoelectric generators and photovoltaic panels, was proposed as a solution. Structure and parametric sufficiency of power supply system were established. Computer model for estimation of autonomous power system effectiveness was developed and validated.

1. Introduction
Nowadays Russia holds one of the leading positions in a global oil recovery share. Most perspective areas of Russia in regards of oil production are Eastern Siberia, Far East, Far North and continental shelf. As these areas are remote from industrially developed part of Russia, the necessity of oil transportation to oil consuming industrial regions by means of pipelines arises. Transportation of oil and oil-products by pipelines is one of the most important tasks of oil industry and oil pipelines are strategic objects [1]. Main dangers for oil pipelines safety are unauthorized incisions, oil leakages and paraffin deposits [2–4].

2. Relevance
Generally, oil pipelines are being constructed in areas with no centralized electrical power supply. Therefore, additional problems with ensuring the operation of leakage detection systems (LDS) and electric drives of stop valves for emergency shutoff of oil pipeline fault parts arise. This is especially common for poorly developed arctic areas of Russia, where about 60% of oil is produced [5]. In this regard, 20% of oil transportation expenditures are connected with electric power supply [6, 7].

In order to solve this problem of electric power supply for LDS data collection points and stop valves electric drives, located in oil pipelines, the usage of power sources with self-sufficiency, blast and fire safety, long service life and high reliability is required.

3. Suggested solution
As a solution for this problem, it is suggested to use developed electrical complex, based on thermoelectric generator (UTEG) and photovoltaic (PV) panel [8]. By itself, each kind of these power sources has its own drawbacks, which are limiting their use for power supply of LDS data collection point and stop valves electric drives of oil pipelines.
Main features of combined use of UTEG and PV panels are:
– Service life. This parameter is approximately same for both UTEGs and PV panels and is about 10 to 20 years. As UTEGs are specifically designed for bigger temperature difference (from 200 to 600°C), the reduction of effectiveness due to overheat or unserviceable conditions will not take place. For PV panel power output is reduced by 3% during first two years of service and by 0.45% afterwards, which makes it necessary to use panels with 10% of excess power.
– Maintenance requirement. In this respect, UTEG is not demanding and can operate at any condition. Significant importance is held by ability to provide temperature difference, as output power will be reduced during summer. Otherwise, PV panels can get covered by snow and ice during winter. This is not critical, as UTEG will compensate the lack of power in the meantime. Therefore, effectiveness of one or the other source will be significantly reduced at different times of year (UTEG in summer, PV panel in winter) compensating each over drawbacks [9].

Structural diagram of developed power unit is represented in Figure 1.

4. Computer simulation of electrical system operation
In order to analyze power output of UTEG and PV panel during a year with daily averaged environmental temperature and amount of solar radiation for specific areas, computer model was developed in MATLAB Simulink. As a basis of calculation for computer model, implied LDS data collection point and stop valves location in a segment of oil pipeline Ukhta – Usa was selected.

4.1. Simulation of UTEG
For simulation of UTEG thermoelectric modules TGM-199-1.4-3.5 in number if 150 units were considered. Their characteristics are as follows [10]:
– output power, \( P = 4.9 \text{ W at } \Delta T = 170^\circ \text{C; }\)
– load current \( I = 0.87 \text{ A; load voltage } U = 5.6 \text{ V with } R_l \text{ equal to internal resistance } r = 12.8 \text{ Ohm; }\)
– Seebeck coefficient \( \alpha = 0.0664 \text{ V/K. }\)

4.2. Simulation of PV panel
For simulation of PV panel, Delta SM 250-24 M panel with characteristics represented in Table 1 was used [11].
Table 1. Specifications of photovoltaic panel Delta SM 250-24 M.

| Technology                          | Monocrystal   |
|------------------------------------|---------------|
| Overall dimensions of module       | 1640 x 992 x 40 mm |
| Number of cells                    | 60            |
| Peak power, $P_{\text{max}}$        | 250 W         |
| Voltage at peak power point, $U_{\text{mpp}}$ | 31.65 V       |
| Current at peak power point $I_{\text{mpp}}$ | 7.9 A         |
| Short-circuit current, $I_{\text{sc}}$ | 8.45 A        |
| Open-circuit voltage voltage, $U_{\text{oc}}$ | 37.37 V       |
| Energy conversion efficiency       | 18.19%        |
| Current thermal factor $k_i$       | 0.04%/°C      |
| Voltage thermal factor $k_v$       | -0.38%/°C     |

Photovoltaic cell was represented in simulation by equivalent circuit represented in Figure 2, as it comes most close to represent real photovoltaic cell [12].

![Equivalent circuit of photovoltaic cell](image)

4.3. Simulation of daily average variation of temperature
Variation of temperature in north latitudes has apparent daily course, which can be calculated as [13]:

$$T(t) = \bar{T} + 0.5 \cdot \Delta T \cdot \cos \left( \frac{2\pi (t_{\text{loc}} - t_{\text{max}})}{t_{\text{per}}} \right)$$

where $\bar{T}$ – mean daily atmospheric temperature, °C; $\Delta T$ – daily range of atmospheric temperature, °C; $t_{\text{per}}$ – period of atmospheric temperature cycle (24 h), h; $t_{\text{max}}$ – local time of peak temperature, h; $t_{\text{loc}}$ – local solar time, h.

4.4. Simulation of solar radiation amount
Amount of solar radiation reaching the surface is generally determined by surface geometry, atmospheric permeability and relative sun location. Solar radiation reaching the surface depends on several factors, primarily from latitude and longitude of location. Solar radiation also influenced by climate and geographical specifics of location, state of atmosphere, altitude of sun above sea level and others.

In simulation amount of solar radiation was determined in accordance with NASA data [14].

4.5. Validation of computer model
Validation of UTEG computer model was established by comparison of characteristics, acquired by computer simulation and experimental research [9] as represented in Table 2.

Comparison shows that simulation error for calculated parameters is lower than 5%, therefore, it is possible to establish the validity of a model and use it for analysis of UTEG modules operation.
Table 2. Comparison of UTEG parameters, acquired by computer simulation and experimental research

| Parameter    | Simulation | Certificate | Error, % |
|--------------|------------|-------------|----------|
| Peak electric power, W | 251.29    | 250         | 0.39     |
| Voltage at peak power point, V | 31.2      | 31.65       | 1.07     |
| Current at peak power point, A | 8.05      | 7.9         | 1.41     |

Comparison shows, that simulation error is lower than 5%, therefore, it is possible to establish the validity of a model and use it for analysis of PV modules operation.

4.6. Simulation results

Developed computer model of thermoelectric generators and photovoltaic panel is validated and can be used for estimation of effectiveness of power unit in various climatic conditions.

Figure 3 shows results of simulation of UTEG and PV panels’ operation effectiveness during a year. Results of simulation demonstrate what UTEG is most effective during winter, while PV is in summer.

Figure 3. Simulation of UTEG and PV panels annual operation.
5. Conclusion
Power consumption of LDS data collection point is 5.5 W (for monitoring instruments, sensors, transmitting units) and does not exceeds 45 W for heating of cabinet for monitoring instruments at a negative atmospheric temperature during cold periods of a year. Power consumption of stop valve electrical drives is up to 8.5 kW depending on a type of stop valve and oil pipeline diameter. Operating mode of electrical drives is short-periodic.

Therefore, considering consumption of electric drives and their operating mode, developed power supply system with thermoelectric generators and photovoltaic panels can be applied for oil trunk and oil field pipelines of any diameter. This unit not only solves problems with electrical power supply of LDS data collection points, but also, allows widespread installation, especially in remote areas without centralized power supply. This in turn reduces time required to locate and stop the leakage from oil pipeline, negative impact on environment and financial expenses required for accident elimination.

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