Dependence of power supply systems reliability on the type of redundancy

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Abstract. The paper deals with power supply systems reliability of gas pumping compressor stations. Comparative analysis of the system reliability with hot, warm and cold reserve is processed. The modelling was performed using the software complex "ARBITR". Dependability measures were determined for different types of power supply systems with different set and number of power sources including centralized power supply system, autonomous power stations and others. Recommendations on the use of various types of redundancy for various structures of power supply systems are given.

1. Introduction

Currently industrial enterprises attend to power supply reliability. This is especially important for enterprises with a complex technological process [1, 2]. A break in the power supply of such enterprises leads to production stop for a long time. Therefore, there are requirements for the reliability of power supply in many industries [3, 4].

The required reliability indicators can be achieved through the development of a rational power supply scheme, which combines various sources of electrical energy [5, 6, 7]. Such sources include the centralized power grid, autonomous sources (local power plants based on diesel and gas engines, gas turbines), as well as various power plants based on renewable energy sources [8, 9, 10]. In this case, various redundancy methods can be used that provide power recovery in the required time [11].

There are different types of redundancy: hot, warm and cold reserve. When a reserve is hot, several sources operate in the same mode as the main power source. Each of these sources can provide energy for a whole load. This is a warm reserve when several sources operate with a load less than the nominal value. If one of them fails, the load of other sources increases. Cold reserve, reserved sources operate without load until the primary fails. The type of redundancy largely determines the switching time from one power source to another. Therefore, choosing the right type of redundancy for various power supply schemes is a very important task.

2. Description of the considered system

As an example, the power supply system of the "Rzhevskaya" compressor station is considered. The block diagram of the power supply system is presented in Figure 1. In this scheme, the main sources are the autonomous synchronous generators of the local power station G 1-3. Two generators should work for the normal power supply of electricity consumers of the compressor station. This is a warm reserve, because three generators operate with reduced load. If one of them fails, the other two take over its load. At the same time the external centralized power system is connected.
Figure 1. Power supply system of the "Rzhevska" compressor station. TL - transmission line; CB - Circuit breakers 10kV; D - disconnector; TR - transformer; RP - relay protection; CL - cable line; G - generator; ADPS - autonomous diesel power station; AB - accumulator battery.

Also autonomous diesel power station (ADPS) is provided in the scheme. It is necessary to supply electricity to the most responsible consumers in case of failure of the power plant generators and the centralized power system. In this example, ADPS operate as cold reserve. When a switch to the power supply from ADPS occurs, a certain amount of time passes. This is determined by the start-up time of ADPS, the synchronization time and the necessary switching in the system. In the case of parallel operation of the centralized power system and power plant generators, there will be a hot reserve. This means that no switching is required to provide redundancy. Therefore it will not be wasted time to power recovery.

The variants of the power supply system with hot and cold redundancy were considered in this article. The simulation was performed using the software "ARBITR" [12]. The operation of the software is based on logical-probabilistic modelling of systems reliability with complex structure [13]. The initial data for modelling (time between failures and the recovery time of system elements) were obtained on the basis of statistical data processing [14]. Figure 2 shows the scheme of functional integrity of a system with a cold reserve.
Figure 2. The scheme of functional integrity of a system with a cold reserve: 1 – main source, 2,3 – reserve source, 4,5,6 – circuit breakers, 7 – energy consumer, 8,9 – phantom elements to modeling circuit breakers switching logic during redundancy.

Sources 2 and 3 reserve the main source 1. Circuit breaker 5 of source 2 will close only when source 1 or its circuit breaker 4 is failed. Similarly, circuit breaker 6 will close if the output signals of circuit breakers 4 and 5 are equal to logical zero. Connections between elements symbolize Boolean operations: OR, AND and inversion. This allows you to simulate operation of circuit breakers in case of source failures.

3. Results of modelling
Two cases were considered for the system presented in Figure 1. In the first case, hot reserve was used for all sources of the system. In the second case, warm reserve was used for generators of local power station, cold reserve was used for centralized power system and autonomous diesel power station.

The following reliability indicators were determined: MTBF – mean time between failures, MTTR – mean time to recovery, AF – availability factor, Q(t) – probability of failure per year. The obtained indicators are given in table 1 (1 – for the first case, 2 – for the second).

| Type of reserve | MTBF, hour | MTTR, hour | AF         | Q(t)        |
|----------------|------------|------------|------------|-------------|
| Hot            | 522372     | 12.67      | 0.99997573 | 0.01663     |
| Warm and cold  | 38433      | 86.53      | 0.99775363 | 0.20381     |

From the table it can be seen that electrical power supply system with hot reserve has the best reliability indicators. However, the difference in availability factors is not significant. This increase in reliability can be achieved in other ways, for example using more reliable system elements [14, 15]. It is also necessary to take into account the economic side of the issue, namely the cost of fuel, repairs, etc.

It should be noted that this model did not take into account the time of switching to the reserve sources with the cold reserve. This moment can be decisive for choosing redundancy method for the power supply systems For example, systems with consumers which are sensitive even to short interruptions in power supply.

4. Conclusion
Thus, hot redundancy in structurally complex power supply systems gives a slight increase in reliability indicators compared to warm and cold reserve. From an economic point of view, this type of redundancy also has disadvantages. Especially when autonomous power station are used as reserve source with gas or diesel fuel as the primary source of energy.

The use of hot redundancy can be justified only for industrial enterprises whose technological process is sensitive even the short interruptions in power supply (a few hundredths of a second). In other cases, it is recommended to use a warm reserve or cold reserve, as well as their various combinations.
Acknowledgments
The presented results were obtained as a part of scientific researches according to the contract № 13.3746.2017.8.9 within the scope of the State task.

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