Optimization of Phase Determining Method for Automatic Transfer Switch Operation Based on Simulated Annealing

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Abstract. Fast reserve supply input systems significantly increase the reliability of power supply due to the possibility of preserving the technological process in case of emergency situations. The accuracy of determining the phase of the residual voltage on the busbar in process of connecting the power reserve supply provides a way to significantly reduce the starting overcurrents. In this paper, some modifications of the annealing method for determining the phase of the residual voltage on main section of busbar for emergency mode are considered. The obtained simulation results based on MATLAB environment make it possible to carry out a comparative analysis of a number of calculations for phase estimation design of automatic transfer switch operations based on simulated annealing.

1. Introduction

The reliability of power supply is an important aspect of the economic efficiency of an industrial enterprise and includes issues of both electricity production [1] and its transmission [2,3]. There are methods for predicting the probability of damage to power lines [4-9], which make it possible to assess the economic damage from accidents and choose the optimal level of investment to maintain the necessary level of reliability from an economic point of view. Despite this, not all technological processes allow a break in the power supply, so one of the ways to ensure reliability is the use of backup power sources.

Automation of power backup for responsible consumers [10-12] allows to restore power supply by entering a backup source in case of an accident and power outage of the consumer. One of the difficulties in entering the reserve is taking into account the recharge from the motor load in case of power loss, which can lead to a slowdown in the voltage drop on the main section of the busbar and, as a result, an increase in the response time of the automatic input of the reserve power supply [13].

When entering a backup power source, the appearance of overcurrents may cause the relay protection to be triggered or the electric drive to be damaged, which will lead to the need to restart the technological process [14]. This means that the amount of time spent on determining the loss of power from the main power supply source and the accuracy of pre-synchronization when entering the reserve determines the amount of overcurrents, and, therefore, the success of the emergency automation system to prevent the shutdown of the technological process.

The work of fast automatic transfer switch allowing to significantly reduce the time of entering the reserve is covered in [16-18]. In [19], the algorithm of the fast automatic transfer switch operation is
described, as well as the results of its work, which showed the possibility of maintaining continuous operation of various motor loads in case of an accident on the main section of busbar.

The evolution of adaptive methods [20-22] has opened up opportunities for creating automatic systems that can change the operating parameters depending on the development of an emergency situation. Along with this, flexible logic methods have been developed in automatic systems, which provide opportunities for systems to be automatically taught based on already occurred or simulated emergency situations [23].

Imitation of the annealing method refers to genetic methods for solving optimization problems. The application of genetic methods in the automation and protecting of electric power systems looks like a promising direction [24-25]. The main goal of the work was to simulate the computational costs for determining the phase of the residual voltage on the main section of busbar in emergency mode based on some modifications of the annealing method. The simulation of emergency modes was carried out using the MATLAB software product.

2. Equal probability annealing method

The principle of using the simulation of the annealing method to search for the phase of the motor load when implementing reserve of power source was considered in [26].

The criterion of the optimal solution for determining the phase of the residual voltage on the motor load is the sum of the voltage differences of the backup power supply and the residual voltage on the load buses at a given length of the oscillogram overlay, which is determined according to the expression:

\[ U_{SUM} = \frac{1}{g} \sum_{k=g}^{n} (U_1(k) - U_2(k)) \]  

(1)

Where g and n specify the length of the data window, \( U_1(k) \) – voltage samples on the backup power source, \( U_2(k) \) – voltage samples on the main bus section, \( k \) – the number of the start data window sample.

Figure 1 shows a graphical representation of the process of calculating expression (1).

![Figure 1. Graphical representation of the process of calculating the expression (1).](image-url)
2.1. Initial data of the emergency power supply mode of the motor load

![Figure 2](image_url)

**Figure 2.** Experimental oscillogram of the emergency mode development on the busbar with a motor load.

Region 1 – normal operation mode, 2-emergency region. To determine the best match between the residual voltage on the motor load busbar and the voltage of the backup power source, which was assumed to be equal to 10 kV, the expression (1) is used. To find the voltage phase according to expression (1), a sinusoidal voltage was superimposed on regions 1 and 2 by the shift method, and it was shifted in phase to find the best match (Figure 3).

![Figure 3](image_url)

**Figure 3.** The result of the overlay for region 1.

The initial phase of the signal in region 1 is 5.4 radians, since at this phase the mismatch integral is 0. The smallest value of the mismatch integral for region 2 corresponds to the initial phase of 4.7 radians.

2.2. Parameters used in the annealing method

Figure 2 shows an experimental oscillogram of the voltage on the motor load busbars taken for the annealing method test check before and after the power loss on the 10 kV busbar section. When modeling, the parameters were taken, which are shown in Table 1.
Table 1. Parameters of the annealing method used in the simulation.

| Parameter                                    | Value |
|----------------------------------------------|-------|
| Random phase change on the iteration, rad    | ± 0.1 |
| Width of the data window, ms                 | 20    |
| Number of iterations                         | 500   |

2.3. *Simulation by the equal-probability annealing method*

The algorithm for simulating the annealing method was tested on regions 1 and 2, with an overlay window in one period. The probability of choosing the direction of phase change at each iteration was constant and was 50%.

Figure 5 shows a typical graph of the dependence of the phase change on the iteration number obtained during the annealing method for region 2 (Figure 2).

![Figure 5. Phase dependencies on the iteration number for region 2.](image)

This operation of the algorithm is explained by the fact that the algorithm, as it moves to one of the sides, each time plays with a probability of 0.5 which side to move to at each iteration. Therefore, even with the correct direction of movement, that is, in the direction of decreasing $U_{SUM}$, the algorithm can go back. This increases the number of iterations required and, therefore, the cost of computing resources.

3. *Proposed method of number iterations optimization*

To solve this problem, it makes sense to create a variable probability of choosing a direction with a small phase change at each iteration. At the initial moment of the algorithm's operation, the probability of moving in one of the directions is the same, but as the algorithm works, the probabilities change: if $U_{SUM}$ decreases sequentially as the iterations in any direction increase, then the probability of going in the same direction increases.

The paper considers three variants of changing the probabilities $p$: according to the linear, exponential and parabolic law, as in the expressions (2,3,4):
All these variants were tested on the data region in one period. The obtained graphs for the linear dependence for 5 consecutive simulations with a window in the whole period are shown in Figure 6.

\[ p = x + 0.5 \]  \hspace{1cm} (2)
\[ p = 0.5 \cdot e^x \]  \hspace{1cm} (3)
\[ p = 0.5 + x^2 \]  \hspace{1cm} (4)

Figure 6. The phase change from the iteration number when drawing the phase according to expression (2).

Figure 7 shows graphs of the phase dependence on the iteration number for the exponential dependence for a window in the full period.
Figure 7. The phase change from the iteration number when drawing the phase according to expression (3).

Figure 8 shows graphs of the phase dependence on the iteration number for the exponential dependence for a window in the full period.

Figure 8. The phase change from the iteration number when drawing the phase according to expression (4).
It follows from the obtained graphs that when modeling according to expression (4), the phase fluctuations have a larger spread than when using expressions (2) and (3). In general, it should be noted that there are fewer iterations required to find the phase when using expression (2) compared to the results of modeling according to (3). Therefore, the algorithm for finding the phase based on the use of expression (2) has minimal computational costs.

4. Conclusion
The application of the annealing method to determine the phase of the residual voltage on the main section of the busbar makes it possible to find a global solution that satisfies the most optimal match of the compared signals.

The modifications of the expressions given in this paper for the values of the probability of a small phase change during the draw at each iteration allow us to reduce computational costs. In general, the simulation results show the possibility of using the annealing method in automation systems to determine the residual voltage on the emergency section of busbar.

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