IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

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To cite this article: L S Sabitov *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **915** 012047

Methods of Optimizing the Troubleshooting Parameters of Electric Power Facilities

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Abstract. The paper discusses the methods of optimizing the troubleshooting parameters, based on a combination of heuristic algorithms with the linear integer programming method. The methods are aimed at minimizing costs when creating troubleshooting support for healthy condition monitoring and troubleshooting for in-service and recoverable electronic devices and equipment of electric power systems.

Electric power system are engineering systems consisting of electric components and machinery. In-service safety and cost reduction is ensured by various measures, including the determination of the healthy condition of components, by troubleshooting and monitoring their key performance parameters. The solution to this problem lies in determining the reference points, choosing the optimal troubleshooting parameters and aids, developing algorithms and troubleshooting processes. Methods of combinatorial optimization (abridged enumeration) and heuristic (without enumeration) algorithms are used [1-4] to optimize the parameters.

Optimization of the parameters by the methods of abridged enumeration with a large power of set of many types of condition (hereinafter referred to as the types of condition) and component parameters may require unacceptable expenses of computing resources (time, memory). The use of heuristic optimization algorithms saves computational resources, but does not guarantee obtaining the extreme value of the target function.

The paper proposes a methodology for combining the linear integer programming method with binary variables and heuristic algorithms for optimizing the controlled parameters, aimed at minimizing costs of troubleshooting aids of condition monitoring and troubleshooting of the serviced and recovered electronic devices, and equipment of power systems.

Electronic devices and equipment of power systems are analog and digital features that require routine troubleshooting to facilitate their healthy operation mainly by means of acceptable methods of parameter monitoring, including comprehensive test methods (transitions and digits count and signature analysis) [1]. The object of troubleshooting is set by a state view set E and a parameter set U with known limit values and expenses for troubleshooting aids. The parameters for performance monitoring and troubleshooting are usually redundant.

The authors suggest that the solution to the problem of optimizing the excessive parameters lies in using the unified diagnostic model of continuous and digital electronic objects that defines a binary relation between state types and alternative results of parameter monitoring, for example, in the form of a bipartite digraph:

$$G=(E,U_2,\varphi), \qquad (1)$$

where G is the digraph designation; E is the set of vertices associated with the types of state; U_2 is the set of vertices associated with valid and invalid parameter values; is the set of arcs connecting the vertices from the sets E and U_2.

Arcs of a digraph set the binary relation

$$\varphi: E \rightarrow U_2, \quad (2)$$

according to which alternative types of parameters are compared to each type of state. If the form of the state E_i is manifested by a valid value u_{j1} or an invalid value u_{j0} of the parameter, then an arc connects the corresponding vertices of the digraph (1).

The digraph (1) satisfies the following constraint:

$$\varphi^{-1}(u_{j0}) \cup \varphi^{-1}(u_{j1}) = E, j=1, 2, m, \quad (3)$$

$$\varphi^{-1}(u_{j0}) \cup \varphi^{-1}(u_{j1}) = \varnothing, j=1, 2, m, \quad (4)$$

$$\varphi (E_i) \neq \varphi (E_k), i \neq k, i, k=1, 2, n, \quad (5)$$

where φ^{-1} (u_0), $\varphi^{-1}(u_1)$ are complete inverse images, and $\varphi(E_i)$, $\varphi(E_k)$ are the images of the corresponding vertices; $\varnothing$ stands for an empty set; m is the number of parameters; n is the number of failures.

Conditions (3) - (5) mean that the value of each parameter is known for any kind of state; no kind of state is manifested simultaneously with an invalid and valid value of the parameter; parameters are sufficient to distinguish between types of state in pairs.

The digraph (1) is formed in expert methods and based on circuit simulation of the object. The dimension of the model is determined by the power of many kinds of state and parameters.

Condition (5) in relation to the detection of failure is written as follows:

$$\varphi (E_0) \neq \varphi(E_i), i=1, 2,\ldots, n, \quad (6)$$

where $\varphi(E_0)$, $\varphi(E_i)$ is the image of the vertex associated in digraph (1) with the healthy condition and the failure, respectively.

The sets $\varphi(E_i)$ that make up the failure images that differ with the healthy condition are not empty:

$$|\varphi(E_i)|>0. \quad (7)$$

The choice of the parameters for detecting failures with minimal cost for the troubleshooting aids of monitoring the healthy condition of the object simulated by a digraph (1) is reduced to a linear integer-programming problem with binary variables:

$$\min \sum_{j=1}^{m} c_j x_j , \quad (8)$$

$$\sum_{j \in S_i} x_j >0, \quad (9)$$

where x_j is a variable taking the value 1 if the parameter u_j is selected to detect failure and the value 0 otherwise; c_j is the cost of troubleshooting aids for monitoring the parameter u_j; S_i is the set of parameter numbers, the invalid values of which manifest a failure E_i.

Constraints (9) are formed based on conditions (7). The number of constraints is equal to the number of failures.

The problem of linear integer programming with binary variables is solved by the additive algorithm with the Balas filter (*Balas*) [5, 6, 7]. As a filter, the authors take the costs of the troubleshooting aids for monitoring parameters selected by the heuristic exclusion algorithm.

The set of parameters sufficient to detect failure is generated using the heuristic algorithm by excluding from the digraph (1) the vertices associated with the parameters with the highest troubleshooting costs, the exclusion of which does not breach conditions (7).

Parameters are ranked in descending order of troubleshooting costs. The parameter with the highest troubleshooting costs is selected. The satisfaction of condition (7) is checked for all failures without taking into account the values of the selected parameter. If conditions (7) are satisfied, then the vertex associated with this parameter is excluded from digraph (1). In the event of default of conditions (7) or after excluding the vertices from the digraph, the actions are repeated for the next parameter.

The upper bound on the number of computational operations for excluding vertices from the digraph and checking conditions (7) is estimated by the formula

$$(n+1)m. \qquad (10)$$

With an increase in the number of failures and parameters, the upper limit of the number of calculations increases slowly and almost linearly [8, 9, 10, 11].

The proposed method is applicable for optimizing the controlled parameters by combining heuristic exclusion algorithms with both the Balas method and other methods of mathematical programming, for example, with the branch and bound method [12, 13, 14, 15]

The obvious idea of combining the heuristic algorithm with the method of combinatorial optimization, which has quantitative substantiation in the paper, seems to be one of the possibilities of a compromise between the requirements of reducing complexity and achieving optimal decision-making. A small increase in computing resources in terms of the implementation of the heuristic decision-making algorithm is offset by a significant decrease in computing resources in terms of achieving the optimal solution using mathematical programming. As a result, the cost of computing resources to achieve the optimal solution is significantly reduced. At the same time, combining the heuristic algorithm with the method of combinatorial optimization only partially solves the problem of saving computing resources while optimizing the composition of parameters. Optimization of the object's parameters with a large, albeit limited by heuristic algorithm, power of the set of failures and parameters is achieved at the cost of high computational resources.

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