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The algorithm of economically beneficial overhead wires cross section selection using corrected transmission lines mathematical models

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Abstract

The paper presents an unparalleled electric power system operating mode optimization algorithm aimed to economically beneficial overhead wires cross section selection with respect to electricity rate, electric power system elements price, reliability problem. The algorithm in question allows eliminating the limitation on the maximum allowable wires cross section with the help of corrected transmission lines mathematical models.

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Keywords: electric power system engineering; optimization; wires cross section; method of coordinatewise optimization; equivalent circuit; mutual inductance.

1. Introduction

To date due to the load rise a lot of existing electric power systems (EPS) need to be reconstruct-ed. Also new electric power supply systems are being constructed for a new objects. So the problem of sustainable EPS scheme selection is raised. The conditions of economically advantageous EPS variant choice are system scheme, wires cross section, voltage level, measure of reliability, number of back-up power sources, the number and points of installation of compensating devices. The above mentioned factors in turn determine power, electricity and voltage losses, investments into the EPS under reconstruction or engineering.

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The first step of power system engineering is a loads computation resulting in transformers and wires selection. At the moment according to the Electrical Installations Code the choice of wires cross section is executed on the basis of economic current density. But such a way does not allow to take into account the above mentioned factors in terms of modern EPS. Thus in the [1] reliability of overhead electric transmission lines (OHL) accountance and in [2] the question of reactive power compensation are considered. Moreover the choice of economically advantageous EPS scheme variant, wires cross section in particular, is executed using direct search method that lengthen dramatically the process of EPS engineering on its first steps.

Consequently the algorithm of optimal OHL wires cross section selection should be elaborated. The algorithm in question is supposed to be materialized using coordinatewise optimization method in combination with penalty function approach.

2. Optimization algorithm

Basing on the preplanned EPS scheme and calculated parameters of its operation mode using the methods of matrix math providing certain wires cross section variants the optimal ones are chosen.

To understand the approach of optimal power flow in power systems there are a lot of views. At the [3] authors using the gradient-type interaction prediction approach to define the optimal control problems. The article [4] presents a gravitation search method to find an optimal power flow in a distribution network. The other way in response to this problem is the use of differential evolution method [5]. Power supply systems are described with multi-objective function. In order to address the multi-objective optimal power flow at the [6, 7] algorithms of evolutionary programming, genetic algorithm, and particle swarm optimization are considered. The other way is described at [8].

Authors of this paper offer to solve the problem of multi-objective optimization using coordinatewise optimization method [9, 10].

The optimally criterion is the minimum of EPS construction and operation costs (C) with respect to the electric power supply interruption costs. So target function is computed according to (1)

$$\min C(I + OC_{\Delta P} + IC), \tag{1}$$

where C – aggregate costs, RUR; I - investments into the EPS, RUR; $OC_{\Delta P}$ - cost of power transmission, RUR; IC - electric power supply interruption costs, RUR.

When calculating investments according to (2) it is necessary to take into account wires cost, OHL construction costs, climate region and investments into the switching equipment.

$$I = I_{OHL} + I_{SE}, \tag{2}$$

where I_{OHL} – investments into the OHL construction costs, RUR; I_{SE} - investments into the switching equipment, RUR.

The cost of power transmission is calculated according to (3)

$$OC_{\Delta P} = \sum_{i=1}^{n} \Delta P_i \cdot \tau_i \cdot \beta_i, \tag{3}$$

where n – number of EPS regions; ΔP_i – power losses, kW; τ_i – the using time of power losses, h; β_i – electricity rate, RUR/kWh.

Power losses are calculated with respect to EPS operation mode parameters. Electricity cost is offended by the power supply organization. The using time of power losses according to [2] is to be computed using the following empirical equation (4).

$$\tau = \left(0.124 + \frac{T_{\max}}{10000}\right)^2 \cdot 8760 , \quad (4)$$

where $T_{\max}$ – maximum load utilization time, h [2].

Supply interruption costs are defined by the reliability of the chosen scheme by (5) formula, specifically by the main reliability targets and per unit economical damage, mentioned in [11]:

$$IC = [(pud_s + pud_p \cdot T_{r.t}) \cdot w_t] \cdot p , \quad (5)$$

where pud_s – per unit sudden economical damage, RUR/unit; pud_p – per unit productivity economical damage, RUR/unit·h; $T_{r.t}$ – EPS total recovery time, h; w_t – total failure rate, 1/year; p – average annual productivity, unit·kWh.

Dependent (6) and independent (7) limitations are kept in mind. The first are voltages in EPS nodes, power flows in OHL. The second are loads, admissible voltage losses, permissible continuous current in EPS elements, amount of power given by the power source.

$$\begin{cases} I_{adm} \geq I_{\max}, \\ U_{adm} = \dfrac{U_n \cdot 100\%}{U_{nom}} \leq \pm 5\% \, U_{nom}. \end{cases}, \quad (6)$$

where I_{adm} and $I_{\max}$ – admissible and maximum conductor current, A; U_n – node voltage, kV; U_{adm} – admissible voltage losses of EPS, kV; U_{nom} – nominal voltage of EPS, kV.

$$\begin{cases} S_{load} = \text{const}, \\ P_{\min} \leq P_{gen} \leq P_{\max}. \end{cases}, \quad (7)$$

where S_{load} – power load, kVA; P_{gen} – load-supplying capacitance, kW; $P_{\min}$ and $P_{\max}$ – minimum and maximum power output, kW.

Also it is necessary to mention the power balance of EPS (8)

$$P_{gen} = P_{load} + \Delta P . \quad (8)$$

3. Corrected transmission lines mathematical models

Power flow and losses computation results are defined mostly by the mathematical models of OHL. The away of OHL modeling depends mostly on the aims of the mode computation. Thus the most widely spread way to represent the OHL in the power system steady-mode calculation is the use of their specific parameters [12, 13]. Another way of OHL modeling implies the calculation of lines conductors mutual inductance and capacitance [14]. This model is more accurate, but the scope of its application often limited to the EPS out-of-balance operating conditions computation [15] and place of damage determination in 110 kV network [16].

The modeling of OHL by the specific electric parameters leads to the underprediction of specific impedance and as a result to the overestimation of power losses. The use of such an approach in EPS engineering and optimal wires cross section choice could result in wrong decision. The authors of the paper suggest to use in EPS under engineering operating mode forecast analysis aimed to its optimization the specific U-shaped equivalent circuit (fig. 1) taking into account not only the model of phase wires, but also their relative position on the OHL tower.

The U-shaped equivalent circuit given in the paper allows to compute OHL parameters as lumped, which keeps the calculation process simple comparing to the use of distributed parameters [17].

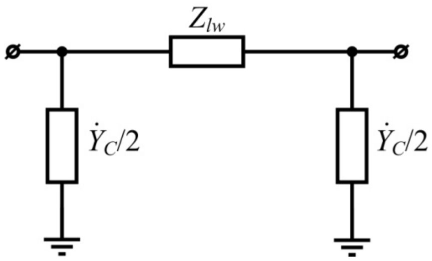

Fig. 1. U-shaped equivalent circuit of OHL.

Lenghtwise impedance is formed by the impedance of “wire-ground” conductor $\dot{Z}_L$ and mutual inductance between phase wires of one and the same circuit $\dot{Z}_M$ which diminish equivalent lenghtwise impedance. The active part of “wire-ground” impedance is the sum of wire resistance r_w and r_g resistance which takes into account the losses of active power because of current flow in the ground and equals 0.05 Ω/km [18]. Reactive part of above mentioned impedance depends on the equivalent return conductor depth in the ground D_g, which equals 935 m, and equivalent conductor radius $\rho_{c.e}$ (9):

$$\rho_{c.e} = k \cdot \rho_w \,, \tag{9}$$

where ρ_w – real wire radius; k – factor, considering the inner magnetic field of the conductor and equals 0.779 for solid round cross section conductors made of nonmagnetic materials, 0.95 for aluminium steel supported conductor, 0.82 for aluminium steel supported conductor with two or three lay-ups.

Mutual inductance impedance depends on the r_g, equivalent return conductor depth in the ground D_g and geometric mean distance between the phase wires D_m, which for the single-circuit OHL is:

$$D_m = \sqrt[3]{D_{L1L2} D_{L2L3} D_{L3L1}} \,. \tag{10}$$

Taking into consideration all the above mentioned information specific lenghtwise impedance is:

$$\dot{Z}_{lw} = r_w + i0{,}145 \lg \frac{D_m}{\rho_{c.e}} \,. \tag{11}$$

To calculate the capacitance of OHL the important initial condition is capacitance between phase conductors and ground which with respect to the method of electrical images [19, 20] is:

$$C = 1 / \left(\alpha_{own} - \alpha_{mut} \right), \text{ F/km} \tag{12}$$

where α_{own} – own potential coefficient (13), α_{mut} – mutual potential coefficient (14).

With the knowledge of the distance between phase conductor and its electrical image S_{pp} it is possible to calculate own potential coefficient:

$$\alpha_{own} = 41.4 \cdot 10^6 \cdot \lg \left(\frac{\sqrt[3]{S_{L1L1} S_{L2L2} S_{L3L3}}}{\rho_w} \right). \tag{13}$$

Mutual potential coefficient is calculated with the help of distance between the conductor of one phase and electrical image of another $S_{pp'}$:

$$\alpha_{mut} = 41.4 \cdot 10^6 \cdot \lg\left(\sqrt[3]{\frac{S_{L1L2}S_{L1L3}S_{L2L3}}{D_{L1L2}D_{L1L3}D_{L2L3}}}\right). \qquad (14)$$

Putting (13) and (14) into (12) the equitation for calculation of capacitance between OHL wires and ground is formed:

$$C = \frac{0.241 \cdot 10^{-6}}{\lg \dfrac{D_m \sqrt[3]{S_{L1L1}S_{L2L2}S_{L3L3}}}{\rho_w \sqrt[3]{S_{L1L2}S_{L1L3}S_{L2L3}}}}. \qquad (15)$$

Specific capacitive admittance of OHL:

$$\dot{Y}_C = i2\pi fC. \qquad (16)$$

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