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The method of determining marginal costs of energy transmission in power network

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Abstract

This paper outlines "point to point" method of allocating the marginal costs of energy transmission in power network to receiving nodes of the network, based on redistribution of line flow in the network onto shares originating from respective nodes charge allocation. Presented results of the marginal costs calculation of energy transmission were carried out in closed network.

Keywords: Marginal cost; Energy transmission

1. Introduction

The categories of costs, which are of great importance in business of supplying electrical energy, are the marginal costs of transmission of it. It is recognized that the prices of the energy based on marginal costs, are providing suitable indications for decision makers in the industry. Essential component of the marginal cost of energy supply to ultimate consumers is marginal cost of energy transmission trough high voltage and distribution networks. Difficulties in precise prediction of power and energy demand by the consumers in particular nodes and large fluctuations in that demand thorough a period of one year and next years of assumed horizon of planning is inducing the necessity of repetitive reckoning of marginal cost of energy transmission. In other words it is essential to implement effective methods allowing for taking into consideration all essential constituents of marginal costs of energy transmission to all receiving nodes of case network.

The paper is introducing the outline of calculation methods in determining marginal costs of energy transmission to each receiving node of closed network. It is presenting as well the results of calculations for case network.

2. Short-term marginal costs of energy transmission incurred in electrical networks

Theoretically, marginal costs of energy transmission to each node of the network can be calculated using direct method, by changing consecutively amount of load to each of the nodes by 1 MW. This method of calculation is ineffective though and demands a lot of effort to be put into it. The method described in this paper eliminates that inconvenience.

The first step in the proposed method of estimating the marginal costs of power and energy transmission to receiving nodes of electrical network is to determine for each interval of load curve in power network, what part in power flow in each line is coming from load of particular receiving node [1].

Power flows in case network are described by the relationship accordingly for active and reactive power [1]:

$$P_l = \sum_{k=1}^{K} \lambda_{l,k} P_l \quad Q_l = \sum_{k=1}^{K} \gamma_{l,k} Q_l \tag{1}$$

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where $\lambda_{l,\,k}$, $\gamma_{l,\,k}$ are the factors of node k load share during power flow, accordingly active and reactive in line l. P_l and Q_l – power flows in line.

Using correlations (1) apparent power in line l is defined by equation:

$$S_l = \sum_{k=1}^{K} \zeta_{l,k} S_l \tag{2}$$

where $\zeta_{l,\,k}$ is the factor of node k load share in apparent power flow of line l.

Using correlation (2) cost increase in active power loss in s interval of load curve initiated by unitary changes of power load in receiving nodes, is defined by equation [2]:

$$\Delta C_{L,s} = (\xi_1 + \cdots + \xi_k + \cdots + \xi_K) \cdot \Delta C_{L,s} \tag{3}$$

where ξ_k is the factor of load share in k node in increase of costs in active power loss in network during chosen time interval, whereof the sum is: $\sum_{k=1}^{K} \xi_k = 1$.

While analyzing shares of load in particular nodes in power transmission in lines, which could be overloaded in case of power delivery to nodes due to the demand calculated, cost growth from non-supplied energy due to limited capacity of the network, can be defined by the following formula [2]:

$$\Delta C_{\mathrm{NS},L} = (\tau_1 + \tau_2 + \cdots + \tau_k + \cdots + \tau_K) \cdot \Delta C_{\mathrm{NS},L} \tag{4}$$

where τ_k is the load share of the node k in cost change of non-supplied energy due to limited capacity of the network, initiated by unitary changes of power load in the respective nodes. Analogically the sum in the brackets in the Eq. (4) is equal (1). Similar like in all subsequent formulas in which elements, indexed from 1 to K are summarized.

Cost growth from non-supplied energy due to failure of the element l can be defined by the following dependence [2]:

$$\Delta C_{\mathrm{NS},F,l} = (\tau_{1,l} + \cdots + \tau_{k,l} + \cdots + \tau_{K,l}) \cdot \Delta C_{\mathrm{NE},A,l} \tag{5}$$

where $\tau_{l,k}$ – is the load share in the node k in change of costs due to non-supplied energy in case of failure of line l initiated by unitary changes of power load request in receiving nodes of the network.

Therefore total cost change of undistributed energy due to a malfunction will equal:

$$\Delta C_{\mathrm{NS},F} = \sum_{l=1}^{L} \left(\sum_{k=1}^{K} \tau_{l,k} \cdot \Delta C_{\mathrm{NS},F,l} \right) \tag{6}$$

where L – is the number of lines in respective network.

Exploiting the dependence (3)–(6) short-term marginal cost of power and energy transmission in zone s can be defined as [2]:

$$\mathrm{STMCPT}_s = (\sigma_1^{\mathrm{PS}} + \cdots + \sigma_k^{\mathrm{PS}} + \cdots + \sigma_K^{\mathrm{PS}})\mathrm{STMCPT}_s \tag{7}$$

$$\mathrm{STMCET}_s = (\sigma_1^{\mathrm{ES}} + \cdots + \sigma_k^{\mathrm{ES}} + \cdots + \sigma_K^{\mathrm{ES}})\mathrm{STMCET}_s \tag{8}$$

where $\sigma_k^{\mathrm{PS}}, \sigma_k^{\mathrm{ES}}$ – are the respective shares of reception of power and energy accordingly in particular network nodes in short-term marginal costs of transmission.

3. Long-term marginal costs of energy transmission in electrical networks

For requirements of analysis of power and energy transmission in network two categories of long-term cost of marginal transmission are used:

Current long-term marginal cost (CLTMC) defined as transmission cost growth caused by unitary rise of demand of power and energy in conditions when mentioned rise causes the necessity to boost the transmission ability of the network incurring on this purpose capital expenditure.

Equivalent long-term marginal cost (ELTMC) obtained from LTMC trough allotment on equivalent values equal throughout all years included in analysis, in each differed zones of loads. Further in this paper this category of cost will be treated as long-term marginal cost (LTMC).

Long-term marginal cost of power transmission is determined from following dependence [2]:

$$\mathrm{LTMCP}_y = \sum_{t=T_\mathrm{i}}^{T_\mathrm{f}} a_t \frac{\Delta C_\mathrm{P}(t) \cdot (1+p)^{-(t-\mathrm{YR})}}{\Delta P(t) \cdot (1+p)^{-(t-\mathrm{YR})}} = \sum_{t=T_\mathrm{i}}^{T_\mathrm{f}} a_t \cdot \mathrm{CLTMCP}\ (t) \tag{9}$$

where T_i, T_f is accordingly initial and final year of analyzed time interval, ΔC_P (t) – total cost growth of power transmission in year t, ΔP (t) – rise in power demand in year t, a_t – ratio of marginal costs distribution incurring in year t onto annual rates assigned, in analyzed time interval, p – interest rate, YR – year of reference, CLTMCP (t) – current long-term marginal cost of power transmission in year t.

As it is shown in Fig. 1, factor a_t is calculated from the dependence below:

$$a_t = \frac{p}{(1+p)^{(T_\mathrm{f}-T_\mathrm{i})} - 1} \cdot (1+p)^{T_\mathrm{f}-(T_\mathrm{i}+t)} \tag{10}$$

Annual long-term marginal cost of energy is defined by equation [2]:

$$\mathrm{LTMCE}_y = \sum_{t=T_\mathrm{i}}^{T_\mathrm{f}} a_t \frac{\Delta C_\mathrm{E}(t) \cdot (1+p)^{-(t-\mathrm{YR})}}{\Delta A(t) \cdot (1+p)^{-(t-\mathrm{YR})}} = \sum_{t=T_\mathrm{i}}^{T_\mathrm{f}} a_t \cdot \mathrm{CLTMCE}(t) \tag{11}$$

where ΔC_E (t) – is the cost growth in energy transmission to power network nodes in the year t, ΔA (t) – growth in energy demand in year t, CLTMCE (t) – current long-term marginal cost of energy, further notations as in Eq. (9).

Comprehensive analysis of network operation in "long time intervals" requires the familiarity with hourly marginal costs of energy transmission to each receiving node of the network in each of differed curve zones of network load.