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OPTIMIZATION OF CONNECTION SCHEMES AND OPERATING MODES FOR RENEWABLE ENERGY SOURCES IN LOCAL ELECTRIC SYSTEMS

The problems of upgrading of work of renewable energy sources is examined in this work, namely decline of level of losses and increase of level of quality of electric power. For receipt results was modelling the mode optimality conditions for local electric systems with renewable energy sources by complex criteria, as well as developing a mathematical model for evaluation of power losses sensitivity in local electric systems to changes of renewable energy sources power generation will allow to create conditions for providing efficient local electric systems functioning. The presented method showed that the consideration was reduced by the disappearance of renewable energy sources by the criterion of electricity operation and by the criterion of loss of electricity in its transportation, the effective functions of the functioning of the related energy sources in the local electrical systems at the design stage. As a result, the values of the weighting coefficients were obtained, which optimally set the renewable energy sources power in local electric systems and optimize their daily modes. In parallel to this study, it was shown that in order to calculate electricity losses, it is necessary to take into account the bidirectional flow of electricity during the calculation of the load factor shape factor.

Keywords: renewable energy sources, local electrical systems, power losses, modes, network.

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ОПТИМІЗАЦІЯ СХЕМ ПРИЄДНАННЯ ТА РЕЖИМІВ ФУНКЦІОНУВАННЯ ВІДНОВЛЮВАНИХ ДЖЕРЕЛ ЕНЕРГІЇ В ЛОКАЛЬНИХ ЕЛЕКТРИЧНИХ СИСТЕМАХ

У даній роботі розглядається питання підвищення якості роботи відновлюваних джерел енергії, а саме зниження рівня втрат і підвищення рівня якості електроенергії. Задля отримання даних було проведено моделювання умов оптимальності режиму локальної електричної системи з відновлюваним джерелами енергії за комплексним критерієм, який враховує прибуток від продажу електроенергії, її якості та втрати на транспортування електричними мережами, а також розроблено математичну модель для оцінювання чутливості втрат потужності в локальних електричних системах до змін потужності генерування відновлюваних джерел енергії. В результаті отримали значення вагових коефіцієнтів, за яких досягається оптимально встановлена потужність відновлюваних джерел енергії в локальних електричних системах та оптимізації їх добових режимів.

Ключові слова: відновлювані джерела енергії, локальні електричні системи, втрати електроенергії, режими, мережа.

Introduction

Problem of renewable energy sources (RES) functioning optimization in local electric systems with the aim to increase revenue, providing qualitative power supply to consumers and decrease of power losses nowadays is still not much studied [1]. Important thing here is studying RES influence to local electrical systems (LES) operating modes, and also considering interference of LES parameters, at the same time.

RES owners are often forced to compensate baselessly overstated normative power losses to electric power market or to third parties. For example, for small hydropower plant (SH) compensation of losses may reach up to 20% from supplied electric power. This, in its turn, leads to reduction of profitability expected from investments to SH building and restoration.

Studying of RES functioning with the aim to optimize the place of their connection by the criteria of minimal power losses in LES, modelling of mode optimality conditions for LES with RES by complex criteria, as well as developing a mathematical model for evaluation of power losses sensitivity in LES to changes of RES power generation will allow to create conditions for providing efficient LES functioning.

So, in this article problems of calculating optimal power of RES in LES and forming optimality conditions of their functioning by complex criteria that considers revenue from electric power sale, its quality and losses for transferring by power networks are solved.

Methods

Considering the specifics of providing LES profitability, it's worth solving the problem of calculating the optimal power of conditionally controlled renewable energy sources P_j^{RES}, $j = 1,2\ldots n$ by complex criteria that takes into account conditions of multilevel power market tariff u_j and indexes of LES functioning efficiency. As components of optimality criteria for functioning showings of the mentioned above system it's worth using power quality showings and losses for its transfer by LES networks [2] to provide maximum revenue from their electric power realization.

Depending on the goal set, the mentioned problem may be solved as a design problem – to define optimal established power, and as exploitation one – to optimize daily modes of renewable energy sources operation, according to prognosticated LES load schedule.

Method of calculating optimal established power of renewable energy sources in local electric system

To solve the problem of calculating optimal established power by complex criteria considering the specifics of providing LES profitability, it's worth using such an expression of total revenue from RES functioning, connected to parallel work in LES:

$$\mathrm{C}^{\mathrm{RES}} = \sum_{j=1}^{n}\left[\mathrm{z}_{\mathrm{j}} \cdot P_j^{RES} \cdot k_{f_j} \cdot T\right], \quad (1)$$

where P_j^{RES} – established power of RES *j*, kW;

z_j – tariff for electric power production by *j* RES («green tariff»), kop/kW·hour;

k_{f_j} – factor of using established power of *j* RES;

T – load schedule duration, hour

Considering (2.1), target function of the problem on choosing optimal established power of renewable energy sources in LES looks like:

$$\mathrm{F} = \mathrm{C}^{\mathrm{RES}} \cdot e^{-z_1} \cdot e^{-z_2} \to \max \quad (2)$$

with restriction:

$$\sum_{j=1}^{n} P_j^{\mathrm{RES}} - \sum_{g=1}^{m} P_{1_g} \le P_{\lim} \quad (3)$$

where e^{-z_1}, e^{-z_2} – exponential dependencies that determine level of influence of optimality functioning criteria;

$z_1 = k_1 \cdot (1 - \overline{P}(U\mathrm{y}_{\mathrm{allowable}}, T))$ – index of regression equation that considers limitation of revenue from RES functioning by criteria of electric power quality;

$z_2 = k_2 \cdot (1 - \overline{P}(\Delta W_{\mathrm{allowable}}, T))$ – index regression equation that considers limitation of revenue from RES functioning by criteria of electric power losses to its transfer;

k_1, k_2 – weight coefficients of regression equation, for correction of fractional optimality criteria influence to optimization results;

$\overline{P}(U\mathrm{y}_{\mathrm{allowable}}, T)$ – probability of providing normative power deviation for established reporting period *T*;

$\overline{P}(\Delta W_{\mathrm{aloowable}}, T)$ – probability of providing normative power losses for established reporting period *T*;

P_{l_g} – load power of *g* consumption node, *g* = 1,2…*m*;

$P_{\lim}$ – carrying capacity of LES in electric networks that is limited by the weakest area of the network.

Value of RES optimal established power in conditions of multistage power market tariff z_j and keeping limitations on carrying capacity of power lines and power quality in LES will be the solution for optimization problem (2).

So, method of calculating optimal established power of renewable energy sources in a local electric system was suggested, that creates preconditions for increasing functioning efficiency of renewable energy sources in local electric systems at the stage of design. This occurs due taking in consideration limitation of revenue from RES functioning by criteria of electric power quality and criteria of power losses that happen during its transfer, as well as correcting influence of optimality partial criterion to optimization results.

Method of optimization daily generation modes of renewable energy sources in local electric system

Problem of optimization daily modes of renewable energy sources optimization according to prognosticated load schedule of local electric system is shown [2]. Array of *n* controlled RES (on example of SH) and array of conditionally controlled – wind and solar farms, expected value of total revenue from their functioning is:

$$M_t^{\Pi} = \mathrm{c}_{\mathrm{WF}}\, M_t^{\mathrm{WF}} + \mathrm{ц}_{\mathrm{SPP}}\, M_t^{\mathrm{SPP}}. \quad (4)$$

where $\mathrm{ц}_{\mathrm{WF}}$ – tariff on electric power production by *j* RES, kop/kW·hour;

$\mathrm{ц}_{\mathrm{SPP}}$ – tariff on electric power production by *j* SPP, kop/kW·hour.

Conditionally controlled and instable power sources like WF and SPP in target functions and limitations of optimal control problems are presented by expected value of time dependence of electric power generation M_t^{WF}, M_t^{SPP} for time period $t \in [t_0; t_k]$.

In the capacity of control variables, SH electric capacities are taken, as they are the less dependent from influence of environment and may alter within rather wide limits not leading to notable losses of energetic potential of primary energy sources. Components of power losses in LES are determined by conditionally controlled RES and small HPP power flows, they are functions from electric capacities of generating last ones and should be considered in target function (2) for exploitation problem of daily schedules optimization.

To solve the mentioned problem (on time period [t_0; t_k]) of controlled energy sources $P_j^{\text{RES}}(t)$, j = 1,2…n (for example, SHPP) considering modes of conditionally controlled sources, the expression (1) becomes:

$$\mathrm{C}^{\text{RES}}(t)=\int_{t_0}^{t_k}\left[\sum_{j=1}^{n} z_j \cdot P_j^{\text{RES}}(t)\right]dt+\sum_t M_{\mathrm{C},t}\,. \qquad (5)$$

According to (2.5), target function of daily modes optimization problem in renewable energy sources in LES will become:

$$\mathrm{F}(t)=\mathrm{C}^{\text{RES}}(t)\cdot e^{-z_1(t)}\cdot e^{-z_2(t)}\to\max \qquad (6)$$

with limitation:

$$\sum_{j=1}^{n} P_j^{\text{RES}}(t)+M_t^{\text{WF}}+M_t^{\text{SPP}}-\sum_{g=1}^{m} P_{1_g}(t)\le P_{\text{lim}} \qquad (7)$$

where $z_1(t)=k_1\cdot(1-\overline{P}(U\text{y}_{\text{allowable}},t))$ – index of regression equation that considers limitation of revenue from RES functioning by criteria of electric power quality, at time moment t;

$z_2(t)=k_2\cdot(1-\overline{P}(\Delta P_{\text{allowable}},t))$ – index of regression equation that considers limitation of revenue from RES functioning by criteria of power losses on its transfer at time moment t;

$\overline{P}(U\text{y}_{\text{allowable}},t)$ – probability of providing normative deviation of voltage at time moment t;

$\overline{P}(\Delta P_{\text{allowable}},t)$ – probability of providing normative power losses at time moment t.

Values of optimal generation powers of single RES P_j^{RES} according to prognosticated LES load schedule by complex functioning criterion will be the solution for optimization problem (6).

Optimization of daily modes expects involvement of controlled energy sources (for example, SHPP) as balancing for capacity to keep optimal total power of the complex of RES in LES according to (6).

To solve problems (2, 6), there is a set of methods and approaches [3] that are widely applied in power industry [4] to find numeral solutions appropriate to an array of incoming data (current vector of system's condition). Algorithm realization and examples of solving mentioned tasks is given in next chapters.

Results

Regression dependencies $e^{-k_1\cdot(1-\overline{P}(Uav_{\text{allowable}},T))}$, $e^{-k_2\cdot(1-\overline{P}(\Delta W_{\text{allowable}},T))}$, suggested in clauses 1 and 2 are exponential functions. Their power indexes consider limitation of revenue from RES functioning due to inadequate electric power quality and electric power losses to its transfer.

Weight factors of regression equation that define the degree of influence of optimality functioning criteria may be defined with the use of expert evaluation method, use of correlation analysis, graphs method, method of extreme and nominal values, methods of regression analysis and other economic and mathematical methods [5].

Considering index dependencies in expressions (2) and (5), it is thought reasonable to use methods of regression analysis [6] that consists in analytical finding of weight factors on regression equation basing on statistical information.

According to rules of using electric power [7], in case of supplying electric power that has quality parameters out of indexes limits mentioned in agreement on power supply, the supplier of electric power by regulated tariff is responsible before consumer in the amount of twenty five percent of cost of such power amount. That means, at certain assumption that profit from RES exploitation for indicated time period will make up 75% from total revenue.

So, value of weight factor k_1 of regression dependence may be defined for extreme conditions $\overline{P}(U_{av_{\text{allowable}}},T)$=0 and $\overline{P}(U_{av_{\text{allowable}}},T)$=1 from exponential function:

$$e^{-k_1\cdot(1-0)}=0{,}75;\quad k_1=-\ln(0{,}75)=0{,}288\,.$$

At condition of keeping normative deviation, in other words, in case when $\overline{P}(U_{av},T)$=1, established value of weight factor of regression dependence will not influence on optimization results.

With the aim of compliance testing of attained weight coefficient, a set of calculations was made and accordance between statistical data and offered regression dependence was examined (fig. 1). Factor of regression dependence correlation is equal to 0,995, this testifies about high adequacy of formed mathematical model to statistical data.

Weight coefficient k_2 is defined with consideration of «Order of calculating payment for transfer of electric energy of own production at electric power supply by non-regulated tariff» [8]. According to [9] volume of technological expenses at electric power transfer in condition of supplying electric power, for example, to consumers of II class (at voltage degree on limits of balance appliance between power producer and power transfer organization 0,4 – 10 kV) is defined by formula:

$$W_{lossIossI} = \frac{W_{cnII}}{1 - k_{EFNTEEP}} - W_{conII} , \qquad r \qquad (8)$$

where $W_{lossIossI}$ – volume of technological expenses when transferring electric power, MW/hour;

W_{cnII} – volume of consumed electric power by consumers of II class MW/hour;

$k_{EFNTEEP}$ – economic factor of normative technological expenses of electric power to transfer of electric power by networks of II class ($k_{EFNTEEP}$ = 0,1292 for PJSC "Vinnytsiaoblenergo" [10]).

Performing the analysis of expression (8), it's possible to define the rate of normative technological expenses to transfer of electric power in electric network of PJSC "Vinnytsiaoblenergo" by local electric networks for II class of voltage to III - IV quarters of 2017 and I quarter of 2018 that makes up $W^*_{loss\,IossI}$≈15% from volume of consumed electric power by consumers of II class MW/hour.

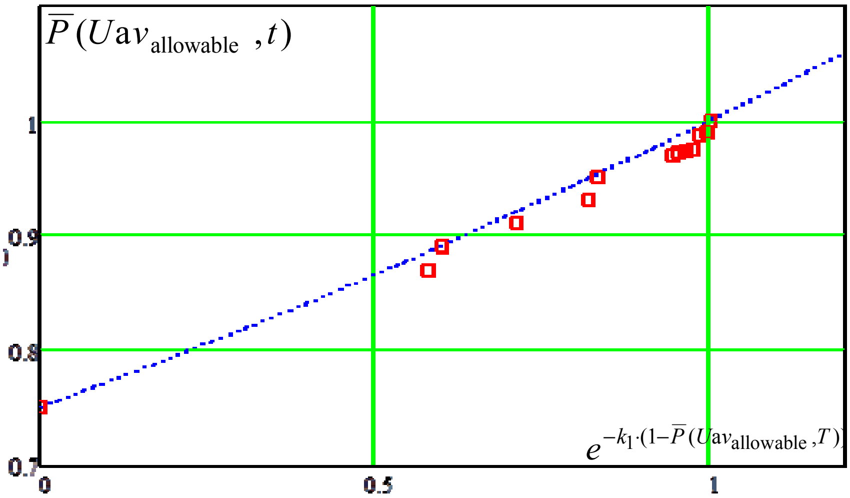

Fig. 1. Graphic display of observation vector for voltage deviation probability and its exponential dependence

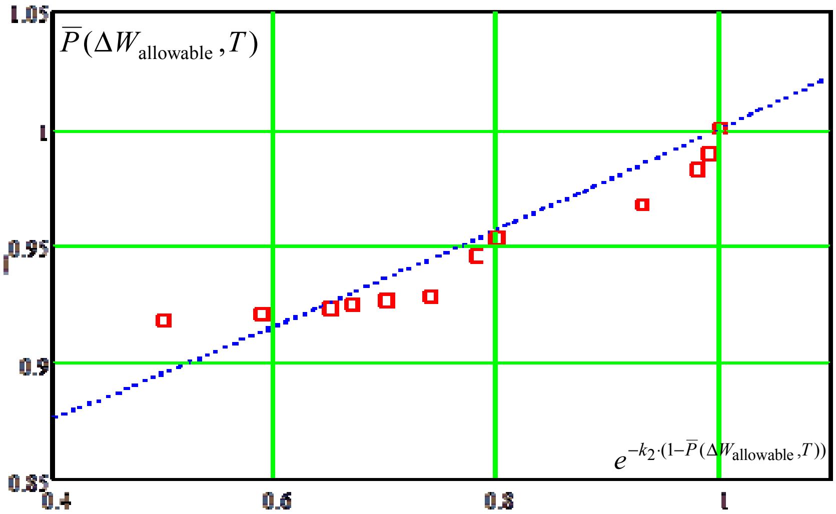

Fig. 2. Graphic display of statistical data of power losses normative deviation and suggested exponential dependency

The mentioned economic factor considers losses to transfer, technological expenses, commercial and other types of expenses related to electric power transfer. That is, relative value of actual losses to electric power transfer by LES networks will not exceed 15%, and normed value is regulated for every distribution network by internal normative documents of electric power supply company according to "Methodical recommendations for defining technological expenses of electric power in transformers and power lines" [10].

So, value of weight factor k_2 of regression dependency may be defined for extreme conditions $\bar{P}(\Delta W_{allowable}, T)$=0 (exceeding of normative technological losses of electric power to transfer of electric power E^{*}_{conII} =85%), $\overline{P}(\Delta W_{allowable}, T)$ =1 from exponential function:

$$e^{-k_2\cdot(1-0)} = 0{,}85\,; \quad k_2 = -\ln(0{,}85) = 0{,}163\,.$$

Correlation factor of attained exponential dependency with statistical data equal to 0,955 indicates about high adequacy of formed mathematical model to statistics data (fig. 2).

So, to solve established problems of defining optimal established power of RES in LES and optimization of their daily modes, it’s necessary to use weight factors k_1=0,288 and k_2=0,163. To calculate electric power losses, it’s reasonable to consider bidirectional nature of electric power flows during calculation of load schedule form factor, and for algorithm implementation – application of numeral methods for solving optimization problems.

Conclusion

From the results of theoretical studies and practical calculations regarding RES influence to EN operation modes it was found out that the problem of defining optimal power of renewable energy sources in local electric systems is reasonable to be solved by complex criterion that considers revenue from RES functioning, electric power quality factors and losses to its transfer by LES networks. When defining the index of electric power quality, it’s worth using the probability of providing normative deviation of voltage and electric power losses for specified report period. This allows to minimize possible disadvantages of design solutions and improve the efficiency of LES functioning.

It was shown that using of provided approach to define optimal established power of renewable energy sources allows to increase the efficiency of local electric systems operation by limiting established RES power, optimal with consideration of electric power quality and power losses, on the stage of design.

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