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Improvement of energy efficiency in distribution Smart grid

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--***ABSTRACT***--
The paper examines the features and priority directions in the construction of the Smart grid. An analysis is made of the main problems related to energy efficiency in the distribution Smart grid. The most significant influencing factors on the energy efficiency of the Smart grid are indicated. The possibilities for achieving energy efficiency in distribution Smart grids are presented.
KEYWORDS: *Smart Grid, energy efficiency.*

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I. INTRODUCTION

In recent years, worldwide, there has been a growing interest in the construction of the Smart Grid, which is the current direction for the development of electricity. With the real-time integration of all participants in the process of production, transmission and consumption of electrical energy through the Smart Grid, the following is achieved [1-10]:

- reduction of costs in the production of electricity from different types of power plants.
- ensuring the balance between production and consumption of electricity at any moment of time.
- ensuring reliable transmission of electrical energy from producers to consumers.
- achieving energy efficiency in the Smart Grid.
- operational response to disturbances in the operation of the electrical network.
- application of modern technologies and decentralized electricity producers based on renewable energy sources.
- implementation of digital devices in the Smart grid.

The aim of the article is to analyze the possibilities of achieving energy efficiency in the Smart grid.

II. ENERGY EFFICIENCY IN THE SMART GRID

One of the requirements for the Smart grid is the achievement of energy efficiency, which is related to:

- choosing the optimal variant of the Smart grid topology to achieve energy efficiency.
- choosing the optimal mode to achieve minimal power and energy losses in the Smart grid.
- the optimization of the Smart grid leading to a reduction in operating costs.

Energy efficiency is a set of measures that reduce the consumption of primary energy sources and lower the energy intensity of electricity consumers. Under the energy efficiency of electrical networks is understood not only the reduction of electricity losses, but also the improvement of the reliability and quality of the electricity supply, the increase of throughput to ensure access of users to the networks. The relative losses of electrical energy in different countries reach from 4 to 40% [11]. All measures related to their reduction are considered as ways to achieve energy efficiency.

Achieving a reduction in energy consumption is regulated by the Energy Efficiency Directive of the European Union (EU) "Horizon 2020" from 2012 [12]. The directive requires member states to set indicative national targets to reduce energy consumption by 20% by 2020. In the revised EU Energy Efficiency Directive: Horizon 2030 of 2018, the proposed target is a 30% reduction in energy consumption by 2030 [13]. The directive requires each EU member state to introduce measures to reduce its annual energy consumption by an average of 4.4% by 2030.

Influencing factors on Smart grid energy efficiency

The management of the electrical energy balance in the Smart grid can be achieved by:

- reducing peak energy consumption.
- encouraging off-peak electricity consumption through energy storage devices such as batteries and electric vehicle charging.

- shifting electricity consumers from peak to off-peak areas in the round-the-clock load schedule where possible.

The factors affecting the energy efficiency of the Smart grid are:

- the amount of electricity consumed in the Smart grid.
- the technologies used in different industries.
- the extraction of energy resources and their distance from the Smart grid.
- infrastructure for transportation, the possibilities and specific costs of storage and consumption of electrical energy.
- restrictions on extraction, transportation, storage and consumption of electricity.

The formulation of criteria for evaluating the efficiency in the Smart grid and the consideration of the influencing factors ensure the optimal choice in the variant studies of the configurations [14,15].

When replacing a generating source with a similar one, then the specific indicators of their efficiency are compared. The coefficient (k_{ef}) of energy efficiency is evaluated:

(1) $$k_{ef} = \frac{A_2}{A_1} = \frac{A_1 - \Delta A}{A_1}$$

where A_1 is the electricity produced by the generating source; A_2 the supplied electricity in the Smart grid; ΔA technological losses of electricity and losses for own needs.

If the energy efficiency of the remaining elements of the Smart grid (power lines, transformers, etc.) is evaluated, the notations in equation (1) are:A_1 the supplied electricity to the corresponding element; $A_2$the output electricity from the corresponding element; ΔAthe power losses in the element.

III. EVALUATION OF THEENERGY EFFICIENCY FOR NON-SYMMETRY AND NON-SINUSOIDAL VOLTAGE IN THE DISTRIBUTION SMART GRID

Voltage asymmetry causes an increase in active power losses in the elements of the electrical network. It is characterized by the asymmetry coefficients of the voltages with reverse sequence k_{2U} and with zero sequence k_{0U}, respectively.

The normal and maximum permissible values of the reverse sequence voltage unbalance factor are 2 % and 4 % respectively.The normal and maximum permissible values of the zero-sequence asymmetry coefficient in low-voltage electrical networks with a nominal voltage of 0.4 kV are 2% and 4%, respectively [11].

The additional losses of active power ΔP_2 in case of voltage asymmetry in the network are expressed by [16]:

(2) $$\Delta P_2 = P_m . \rho_m . k_{2U}^2$$

where$k_{2U}$is the reverse sequence asymmetry coefficient; P_m - the active power in m-th element of the electrical network in the absence of asymmetry; ρ_m the coefficient for the additional losses due to asymmetry.

Non-sinusoidal voltage causes an increase in active power losses. For their calculation, it is necessary to know the nominal powers and voltages of all elements of the Smart grid.The voltage levels of higher harmonics in relative units (U_ν^*) and the corresponding loss factor are determined:

(3) $$\eta_\nu = \sum_{\nu=5}^{13} \left(\frac{(1+0{,}05\nu^2) U_\nu^{*2}}{\nu\sqrt{\nu}} \right)$$

where$\nu$is the sequence number of the accordion; U_ν^* is the voltage of the ν-th harmonic component.

Additional power losses (δP_T) due to non-sinusoidal voltage in transformers in distribution networks are determined by:

(4)$$\delta P_T = (2{,}67 U_2 + 1{,}62 \eta_\nu) \cdot \frac{S_n}{10^{-4}}$$

where$U_2$is the reverse sequence voltage;$S_n$is the rated power of the transformer.

Additional power losses (δP_W) due to non-sinusoidal currents on power lines are determined by:

(5) $$\delta P_W = (3I_1^2 + 3I_2^2 + \sqrt{2} \sum_{\nu=5}^{13} I_\nu^2 \sqrt{\nu}) . R$$

where$I_1$is the rms value of direct sequence current; I_2 is the rms value of reverse sequence current; I_ν is the current magnitude of the ν harmonic component; ν the number of the harmonic; $R$is the active resistance of the power line.

Sometimes the additional losses due to asymmetry and non-sinusoidality of the mode can be significant and increase by 15-18% the power losses in normal mode. In these cases, it is necessary to provide balancing and compensating devices to achieve energy efficiency.

Achieving energy efficiency by replacing old with new power transformers with improved performance

The sequence of calculations for the achievement of energy efficiency by replacing the old power transformers with an exhausted service life with new ones having the same power but improved design parameters (no-load and short-circuit losses) is as follows:

- The annual electricity savings ΔE_i from the reduction of electricity losses when replacing the i-th type of power transformers for a specific electrical network is determined.
- The percentage distribution ε_i, % of the i-th type of power transformers with different rated powers in the Smart grid is found.
- The annual electricity savings from the replacement of power transformers in the Smart grid are calculated.

(6)$\Delta E_\Sigma = \sum_{n=i}^{m} \Delta E_i \varepsilon_i$.

Switching off a part of the lightly loaded power transformers operating in parallel during changes in the load schedule also allows energy efficiency to be achieved.

IV. CONCLUSION

- Energy efficiency is of particular importance in the construction of a Smart grid, and in order to achieve it, it is necessary to foresee measures both in the design and in the operation of the electricity facilities.
- The benefits of Smart grid development are technical, economic and social: the modes in the electrical networks are optimized, energy efficiency is achieved and quality electricity supply is provided to consumers.
- The additional losses of active power in the case of voltage asymmetry depend on the flowing active power in the elements of the electrical network in the absence of asymmetry, the coefficient for the additional losses due to asymmetry and the square of the coefficient of asymmetry.
- Losses of active power due to voltage non-sinusoidality depend on the type of electrical equipment, their parameters and the levels of voltages from higher harmonics.
- Energy efficiency can be achieved by replacing old power transformers with new ones with improved performance, and also by switching off part of the lightly loaded parallel transformers when changing the load schedule.

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