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DETERMINATION OF VOLTAGE EFFICIENT REGULATION ZONES BY THE SOURCES OF DISTRIBUTED GENERATION WITH INVERTER CONNECTION IN DISTRIBUTION ELECTRIC GRID

The approach to determination of efficient voltage regulation zones by means of distributed generation sources with inverter connection to distribution electric grid is considered on the base of voltage sensitivity analysis in the grid nodes relatively power change in the point of source connection. It is studied, bow the sensitivity of nodes dU_i/dQ_{SDG} is influenced by the location of on load tap-changing transformers and which of these nodes are most sensitive relatively this change. Such study allows to determine, in what cases and at what transformer the switching of on load tap-changing should be done in order to minimize the amount of reactive power, that the source of distributed generation spends for voltage regulation in electric grid in order to increase the efficiency of voltage regulation in distribution electric grid (DEG) with the source of distributed generation (SDG). For further research efficiency function of optimal voltage regulation at the expense of coordination of SDG and LTC transformer operation is formed.

Key words: *distribution electric grid, sources of distributed generation, LTC transformer, zones of voltage efficient regulation, reactive power, sensitivity.*

Introduction

In recent years the share of distributed generation (in the given paper alternative sources of energy of small power, decentralized in electric grid are meant) in UES of Ukraine considerably increased [1], and nowadays realization on numerous projects dealing with connection of such sources to electric grids to overcome the dependence on traditional types of fuel is planning.

In the process of integration of the distributed generation sources their considerable impact on the operation of distribution electric grid (DEN), its parameters variations, particularly, voltage, is observed. That is why, voltage regulation in distribution electric grid (DEN), when sources of distributed generation (SDE) operate in it, is the problem of great importance.

Requirements [2] regulate cases, when SDE with the inverter connection can participate in voltage regulation at the expense of active and reactive power change. Numerous of home and foreign papers are devoted to this problem [3 – 6].

To increase the efficiency of voltage regulation in DEN with SDG it is expedient to coordinate the operation of the station with switchings of LTC transformer position [7 – 8]. That is why, in the given paper it is suggested to determine zones of efficient voltage regulation by means of SDG and impact node of LTC transformer.

Voltage regulation by means of SDG

Regulation of active power of SDG may cause voltage increase in DEN nodes above the admissible level [9]. In this case consumption of reactive power of SDG from the grid is accepted [3 – 6], but losses of power in DEN will grow. Besides, the transition of SDG to partial consumption or generation of reactive power leads to the decrease of generation of active power of the station (Fig. 1) in accordance with the relation:

$$P_{SDG} = \sqrt{S_{SDG}^2 - Q_{SDG}^2} \qquad (1)$$

where S_{SDG} – total power of SDG, P_{SDG} – active power, generated by the station, Q_{SDG} – reactive power, consumed or generated by SDG.

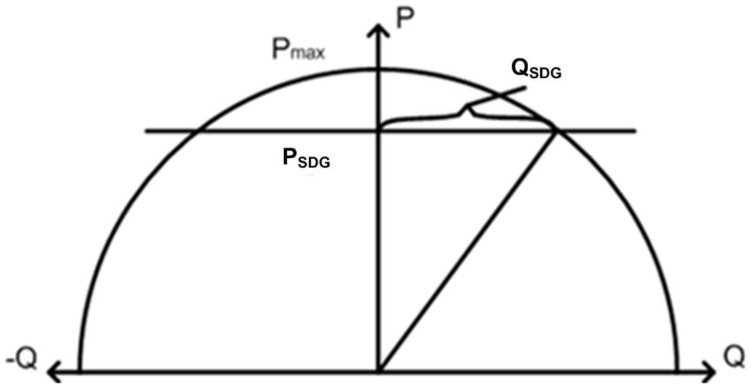

Fig. 1. Characteristic of SDG power

From (1) it follows, that in order to avoid the drop of active power generation of SDG the consumption of reactive power should be minimized, at the same time the voltage must be maintained within the admissible range. On this basis the efficiency function may be formulated:

$$P_{SDG} - \Delta P(Q)_{SDG} - \Delta P_{SDG} \rightarrow max \quad (2)$$

$$\text{if } U_{min} \leq U \leq U_{max} \quad (3)$$

where P_{SDG} – active power, generated by SDG; $\Delta P(Q)_{SDG}$ – value of active power, by which SDG generation must be decreased for partial regulation of its reactive power (according to (1)); ΔP_{SDG} – losses of SDG active power in the elements of power station: in connection transformer, in connection line, etc. Voltage U must be within the range of admissible values (3).

Succession of efficient zones of SDG voltage regulation determination and selection of LTC transformer for increase of regulation efficiency

Proceeding from (2) and (3), it is expedient to know zones, where voltage regulation by means of SDG is the most efficient and how this efficiency is influenced by the position change of LTC transformers, located near SDG, and by what transformer the switching of LTC should be done to improve the efficiency of voltage regulation in DEN with SDG.

The following measures are to be taken:

1. Perform calculation of voltage sensitivity in electric network relatively SDG power change dU_i/dQ_{SDG} and determine nodes with greatest sensitivity - zones of efficient regulation of SDG voltage:

$$dU_i / dQ_{SDG} = \left[dU_1 / dQ_{SDG} \quad dU_2 / dQ_{SDG} \quad \ldots \quad dU_{SDG} / dQ_{SDG} \quad \ldots \quad dU_n / dQ_{SDG}\right] \quad (4)$$

where i – number of DEN node, $i = 1 \ldots n$.

2. Calculate sensitivity of voltage in DEN nodes relatively the change of t^{th} transformer LTC $dU_i/dtap_t$ (t^{th} number of the transformer) that is located near SDG:

$$dU_i / dtap_t = \left[dU_1 / dtap_t \quad dU_2 / dtap_t \quad \ldots \quad dU_n / dtap_t\right] \quad (5)$$

where t – number of the transformer, $t = 1,\ldots,m$; i – number of DEN node, $i = 1 \ldots n$.

3. On the basis of the analysis of the obtained calculations of sensitivity, determine transformers with LTC, which influence the greatest number of nodes among sensitive nodes regarding change of SDG power (i. e. among zones of efficient regulation of SDG voltage);

4. For these transformers the coefficients of operation quality [10 – 11] should be determined and one transformer, regulation of which will promote the increase of voltage regulation in DEN with SDG, should be chosen.

In [10 – 11] it is suggested to choose the transformer with LTC for voltage regulation, based on determination of its coefficient of operation quality, that takes into account reliability characteristics of the transformer (in particular, residual resource), transformer load and sensitivity of power losses change in electric network to LTC switchings of this very transformer. That is, switchings should be done by the transformer, that has the highest coefficient of operation quality.

Thus, for minimization of the consumption or generation of SDG reactive power, switching of LTC position should be done at the transformer, chosen in p. 4. This enables to maximize the generation of SDG active power in accordance with (2) relatively (1) maintaining the voltage in electric grid within admissible limits.

Practical realization

Studies were carried out in the scheme of the fragment of DEN, located in Molochansk district Zaporizhia Region. The scheme has the following voltage levels 150/35/10/6/0,4 kV. Studies were performed in programming complex PowerFactory. The scheme is presented in Fig. 2.

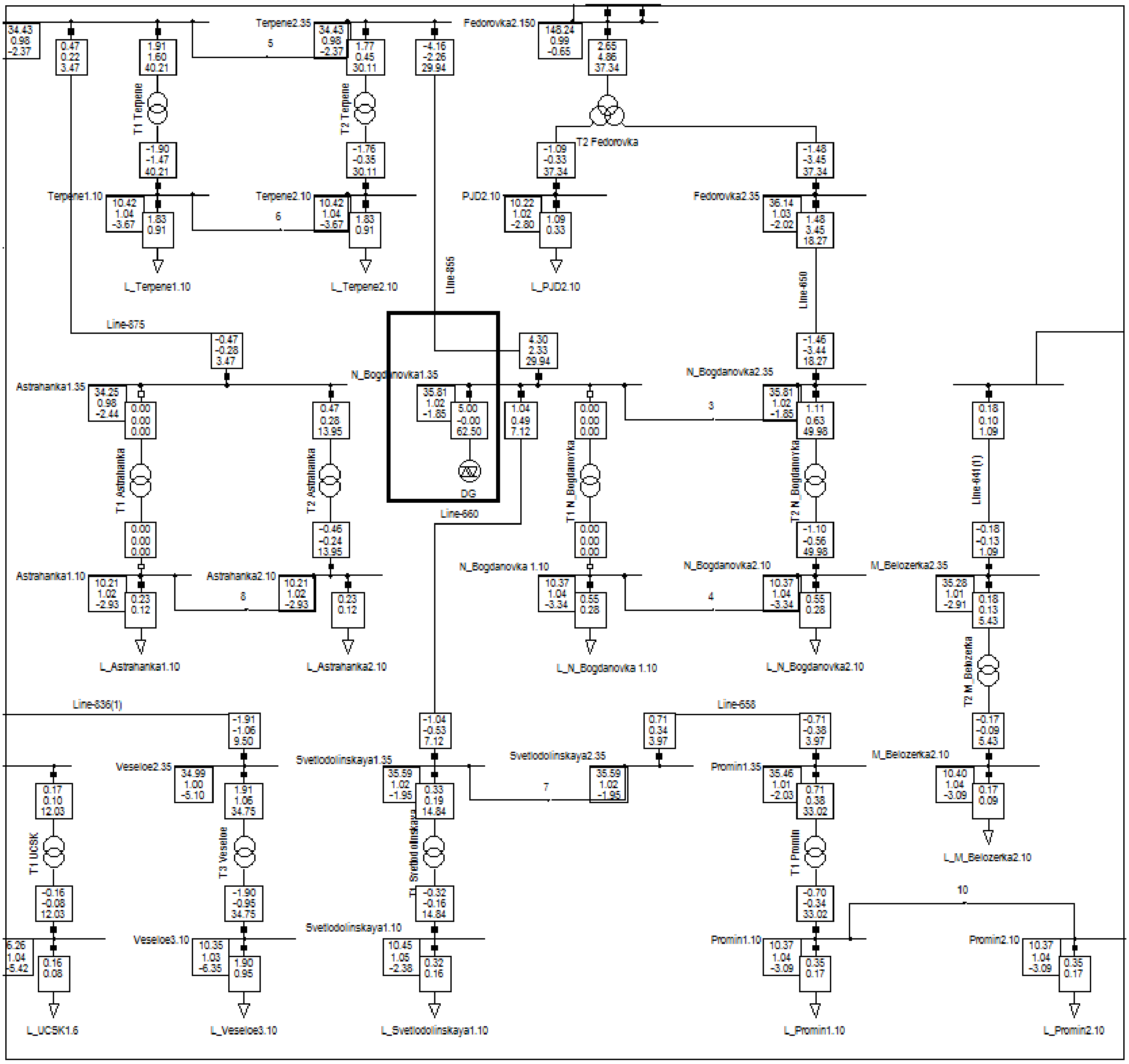

Fig. 2. Fragment of the DEN of Molochanskiy District Zaporizhia Region when SDG is avialable

5 MW SDG is connected to the node N_Bogdanovka1.35 KV. In p. 2 – 4 transformers are considered: T2 Fedorovka, T2 N_Bogdanovka, T2 Terpene, T1 Svetlodolinskaya.

Usually, there arises the question: in what nodes the change of voltage should be monitored for efficient regulation of voltage in DEN, such nodes must give complete characteristic of voltage change in a definite fragment of DEN. One of the variants is to monitor the voltage in the node of power station connection, but such an approach will not be always correct, as loads and generation in DEN constantly change and variations of admissible voltage limits appear not only in the node of SDG connection. For instance, in [12] it is suggested to monitor voltage value in those nodes, where the study has been performed before and it was determined that voltage there may reach maximum/minimum value at different loads and generations. It is more universal approach.

For determination of nodes, where it is expedient to monitor the voltage, the research has been carried out according to [12] and it was revealed that just these nodes are most sensitive, taking into account the calculation of voltage sensitivity in nodes relatively power change in DEN. That is why, for determination of nodes, where the voltage should be monitored, it is sufficient to find nodes with the greatest values of sensitivity. In the given research such nodes are Terpene1.10 and Terpene2.10.

From calculations (Fig. 3) it follows that the greatest sensitivity dU_i/dQ_{SDG} relatively the change of SDG reactive power have the nodes of the substations: Astrahanka, N_Bogdanovka, Promin, Svetlodolinskaya, Terpene and node Fedorovka2.35 (Table 1).

These very nodes are zones of efficient voltage regulation in DEN with SDG, and, hence zones, where the impact of SDG on the voltage is the greatest.

Sensitivities of the voltage in DEN nodes relatively the change of SDG reactive power are shown in Fig. 3.

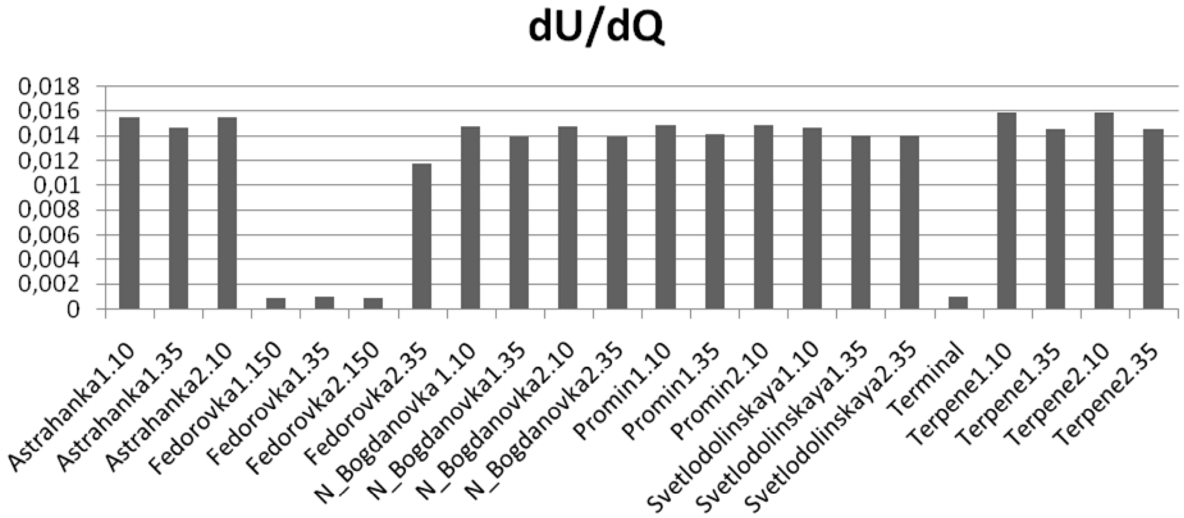

Fig. 3. Sensitivities of the voltage in the nodes of DEN fragment relatively the change of SDG reactive power

As it was mention before, in order to decrease the amount of reactive power, consumed by SDG, to reduce voltage to admissible level, and to reduce power losses in DEN it is expedient, besides SDG power regulation, change the position of LTC transformer. But we should know LTC of what transformer must be switched and now this regulation influences the sensitivity of dU_i/dQ_{SDG} nodes.

Calculation of nodes $dU_i/dtap_t$ sensitivity was carried out according to (5) for transformers with LTC, located near SDG: T2 Fedorovka, T2 N_Bogdanovka, T2 Terpene, T1 Svetlodolinskaya. Results of the calculations are analyzed and proceeding from the results, obtained, the transformer, influencing the greatest number of nodes, located in the zone of SDG influence (in the zone of efficient regulation of SDG voltage) is determined. The results of sensitivity calculation for the transformer T2 Fedorovka are shown in Fig. 4.

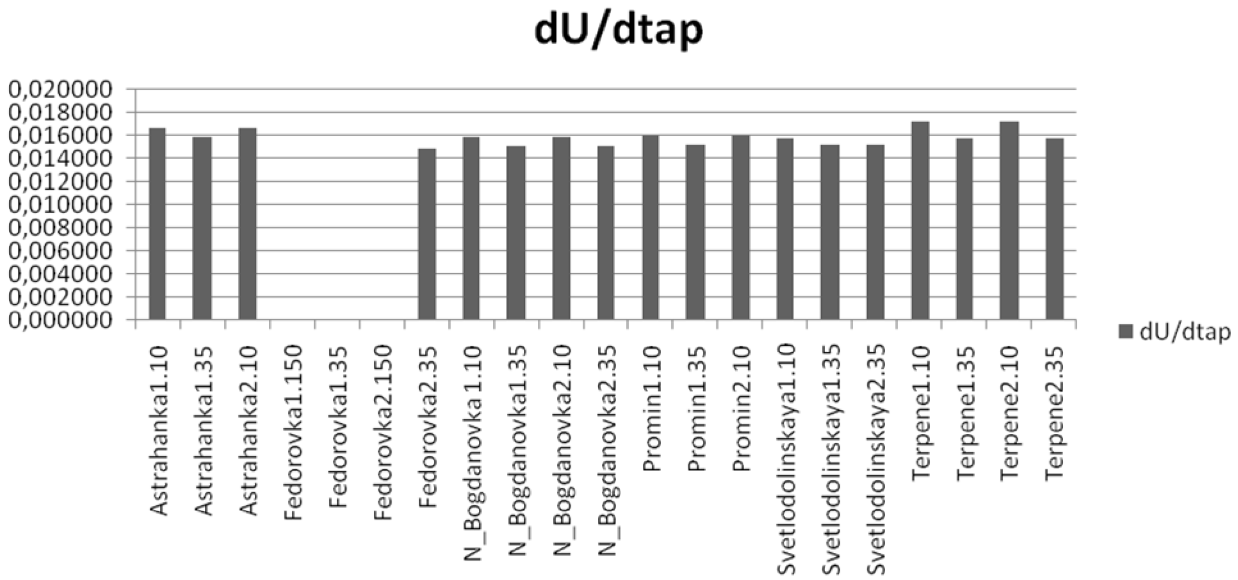

Fig. 4. Sensitity of $dU_i/dtap_t$ nodes relatively position change of LTC transformer T2 Fedorovka

If the number of such transformers was greater, it would be expedient to determine their coefficients of operation quality according to [10 – 11]. Then, the transformer, with the greatest coefficient is chosen.

Thus, LTC switchings of the transformer T2 Fedorovka will promote the reduction of the reactive power amount, that SDG must spend for voltage regulation and it becomes possible to maximize active power of SDG generation according to (2), maintaining voltage within admissible level.

In further research, observing condition (3), it is expedient to determine such optimal solution, when SDG active power is maximized at the expense of reactive power decrease according to (1), number of transformer LTC switchings is minimized to prevent rapid attaining of operation limits of regulation system. If economic expenses are taken into account, efficiency function will have the form:

$$C_{SDG} \cdot (P_{SDG} - \Delta P(Q)_{SDG} - \Delta P_{SDG}) - C_{LTC} \cdot N_{LTC} \rightarrow max \tag{6}$$

where $C_{SDG\Gamma}$ – cost of 1 kW of SDG power, according to documentation concerning «Green tariff»; P_{SDG} – active power of SDG; $\Delta P(Q)_{SDG}$ – value of active power, by which SDG generation should be reduced for partial regulation of its reactive power Q; ΔP_{SDG} – losses of SDG active power in the elements of power station: in the transformer, in connection line, etc.; Np_{LTC} – number of switchings of LTC transformer; C_{LTC} – cost of one LTC transformer switching, based on the cost of LTC system cost and maximum admissible warranty number of switchings of transformer LPC positions.

Conclusion

The paper considers the approach to determination of the zones of voltage efficient regulation by means of sources of distributed generation with inverter connection to distribution electric grid. The approach is based on the analysis of voltage sensitivity dU_i/dQ_{SDG} (i – number of DEN node, i=1...n) in network nodes, relatively power change in the point of source connection. It is determined, what transformers with LTC, located near SDG, influence the greatest number of nodes, being in the zone of SDG influence (in the zone of active regulation of SDG voltage). Such study enables to determine in what cases and on what on what transformer the switching of LTC position should be made to minimize the amount of reactive power, the source of distributed generation spends for voltage regulation in electric grid in order to increase the efficiency of voltage regulation in DEN with SDG. For further research, the efficiency function of voltage optimal regulation at the expense of coordination of SDG and LTC transformer operation, is set up.

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