Investigation of the impact of integrating renewable sources with variable power generation, taking into account restrictions on the voltage stability limit

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Abstract. This article is devoted to the development of a methodology for estimating the amount of balancing power in a system with a large share of renewable energy sources (RES). For this purpose, an analysis was made of the influence of an increase in the installed capacity of wind power plants (WPPs) on the value of the balance power of the energy system, random characteristics of its variability for various combinations of the number of workers in the WPP system. The possibilities of realizing the distribution of balance power in characteristic critical loaded modes of the system are considered. Using the example of a real power system, the wind speed measurement data obtained for the geographic locations of wind stations on the power systems using the developed programs, simulations of the system modes were carried out for various combinations of these stations. The dependences for the balancing power are constructed, the conditions for reducing this power, as well as the conditions for its limitation on the stability of the voltage in the balancing part of the system, are determined.

Introduction

The growth in the share of generation of renewable sources has significantly changed the approaches to the technological implementation of power balancing in the modern energy system. As a result, in the modern energy system, along with traditional sources, with a specified nature of power generation, renewable sources also operate in parallel, a significant part of which are wind turbines and solar PV electrical systems with variable (randomly uncertain) generation. The choice of a balancing source (BS), under these conditions, should provide with a high probability the absolute range of power generation variability (MW), as well as the average value of the slew rate (MW/min) of power generation.

In addition, when choosing a balancing source, it is also important to ensure the stability of the system mode at each step of the variability of the BS generation power.

The generation of electrical energy by renewable sources depends on weather conditions and load [1-3].

Continuous spatiotemporal balancing of the magnitude of deviations between supply and demand in the energy system makes it possible for a stable and reliable power supply. Based only on measurements of random processes of power generation by wind and solar sources, it is not possible to accurately model the magnitude of their variability [4].

The increase in the number of renewable energy sources connected directly to the busbars of the load node of the electrical network of the power system leads to the uncertainty of the consumption forecast [5]. Sources of electrical energy storage (battery systems) are used when there is insufficient power generation to cover the demand of the load to the node to which they are connected [6].

The random and intermittent nature of power generation by wind (WPP) and solar (PV) stations requires the choice of a source for balancing (compensating) the random share of WPP and SPP generation. In most cases, one or two of the existing traditional stations are selected as a balancing source, in which part of the capacity from the total generation is allocated to compensate for the excess or deficit in power generation by the wind and solar stations of the system.

The choice of the value of the set power for the balancing station makes it possible to optimally distribute the load between the stations at different periods of the daily schedule, control the flow distribution in the electrical network of the power system and thereby effectively use the power generation of WPPs and SPPs.

Preliminary research results have shown that for the energy system of Azerbaijan, Shirvan and Sumgayit gas

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turbine stations can be considered as balancing stations, which are connected to 110 kV distribution networks, and are also connected in the supply network of the system at a voltage of 220 kV through lines. It has been established that the probability of overloading lines in distribution networks from fluctuations in the generation of power of a wind station and a solar station is small, which leads to a slight reduction in the generation of these stations.

Power systems with a high share of integrated RES [7-11] present a problem for dispatchers due to intermittent power generation and limitations in their predictability. At some point, the operator may be forced to allow a reduction in wind and solar generation relative to current generation. This amount of reduction in generation from conversion of wind and solar energy can be considered as an opportunity to reduce the total generation in the system. Thus, restrictions arise due to restrictions on power transmission through the supply network or balancing the power in the distribution network between incoming and consumed power [7,8,12]. Therefore, it is necessary to increase the flexibility of the power system in order to increase the production of VRE and at the same time compensate for the discontinuity in the generation of power from these sources [8,13,14]. Some traditional power plants cannot quickly adapt the management of their generation in the system due to technical or economic constraints [4].

Mode restrictions are associated with the speed of set, the duration of the start, as well as the value of the minimum load [8,13,14].

According to the above restrictions, power plants can be classified for use in operational control as not participating in the control process, used in certain situations, or fully accepting control in the tasks of operational maintenance of the system mode [15,16].

The power generation of WPPs and SPPs is intermittent and probabilistic in nature, which does not allow the system dispatchers to use in the operational management of the power system. Power plants not involved in the operational management of the power system, usually these include nuclear power plants, thermal power plants (TPP), which support the base part of the total demand of the power system. Power plants with traditional technology (gas turbines, hydropower plants), as well as all other renewable sources (except wind and solar PV) are involved in the regulation of the regime in the system.

The static stability of the power system in terms of voltage, which is mainly deteriorating due to the overload of backbone transmission lines or the insufficient supply of electric networks of existing traditional power systems with active and reactive power flow control, is facing new problems due to the large-scale integration of variable renewable generation. This article proposes a method for estimating the static stability of voltage in a system with a large share of power generation by wind and solar stations, examines the influence of the number of operating WPPs and SPPs on the mode of a balancing source in order to determine the amount of power generated by it to maintain voltage stability. An analytical criterion has been derived to ensure the stability of the voltage on the tires for connecting WPPs and SPPs to the system for various states of power generation by these stations and the shares of total demand at the current time points. Based on this model, a methodology for optimal system planning is proposed to minimize power generation by a balancing station due to the optimal distribution of active and reactive power generation between renewable sources.

1 Modeling the assessment of the value of the balancing power reserve in the energy system with RES.

Integration of RES into the energy system increases the uncertainty of the generated power and, together with the effect of the uncertainty of the load, makes it impossible to have a strict deterministic description of the value of the balance power.

In general, an estimate of the balancing power can be determined from the following equation:

$$0 = P^{t_i}_{trad.source} + P^{t_i}_{RES} - P^{t_i}_{load} - \Delta P^{t_i} + P^{t_i}_{b.s} \quad (1)$$

Where $P^{t_i}_{trad.source}, P^{t_i}_{RES}$ – capacity of traditional and renewable sources in the daily interval of the daily schedule; $P^{t_i}_{load}$ – load power in the balancing part of the power system in the interval i; ΔP^{t_i} – electrical network losses; $P^{t_i}_{b.s}$ – balancing power value.

In equation (1) $P_{trad.source}, P_{RES}, P_{load}$ are given on the basis of the obtained measurements in a long period of system operation. The value of ΔP, $P_{b.s}$ - balancing power and losses in the network are the desired parameters.

To solve equations (1) with stochastic given input parameters, $P_{trad.source}, P_{RES}, P_{load}$ the latter are given by the limits of their changes in the form of inequality equations, for example

$$P_{\min,RES} \le P_{RES} \le P_{\max,RES} \quad (2)$$

$P_{\min,RES}, P_{\max,RES}$ – are established at the stage of preliminary analysis of stochastic variables P_{RES}.

Thus, the estimation of the values of the balance power $P_{bs,i}$ in each interval $[0,i]$ is reduced to solving the stochastic system of equations

$$0 = P^{i}_{trad.source} + P^{i}_{RES} - P^{i}_{load} - \Delta P^{i} + P^{i}_{b.s}$$

Given the restrictions

$$P^i_{\min,RES} \leq P^i_{RES} \leq P^i_{\max,RES}$$

2 Research on the impact of renewable energy on the power balance in the Azerenerji system

The probabilistic approach in relation to the problem of determining the power reserve for the balance between coverage and demand is caused primarily by the stochastic nature of RES generation. The use of a stochastic approach when choosing a balance power is associated with a probabilistic analysis of observational data on wind speeds and solar radiation over a long observation period, in obtaining a stable assessment of the characteristics of their distribution, obtaining a predictive model for generating power by wind turbines in the geographical area under study and other parameters. At the same time, it is also important to have data on the nature of the stochastic variability of the system load.

Determining the balance power for steady post-accident modes (after failures of its main elements - generators, power lines) will require an analysis of the stability limits of the system state in these modes. The value of the balance during periods of critical conditions, in contrast to the existing deterministic approach, should have a probable estimate, taking into account the uncertainty of the expected emergency conditions. This paper proposes a method for statistical estimation of the limit of static stability of voltage for N-1, N-2 states of the system circuit.

The paper presents the results of calculating the power balance in the national energy system of Azerbaijan with a different combination of power plants with RES for normal and post-accident steady modes and various states of emergency shutdowns of circuit elements. Considering that the basic part of the structure of power plants is (80% of the installed capacity) thermal plants, where it is supposed to place a capacity reserve to cover the imbalance from renewable energy sources, therefore, a very important factor is the placement of a capacity reserve and the determination of flow distribution control strategies in the network.

In 2025, three wind farms are planned to be put into operation in the Azerenergy system: the Khyzi wind farm with a capacity of 240 MW (conditionally named Baku station); WPP Janub 220 MW (Lenkoran) and WPP Shimal 240 MW (Maraza).

To assess the balance capacity and analyze the regimes of the Azerenergy system in connection with the commissioning of the above VRE plants, modeling and computer tests were carried out for the following scheme options:

- WPP "Baku" is connected to the system;
- WPP “Maraza” is connected to the system;
- WPP "Lenkoran" is connected to the system;
- WPP “Baku” + WPP “Lenkoran” are connected to the system;
- WPP “Baku” + WPP “Maraza” are connected to the system;
- WPP “Baku” + WPP “Lenkoran” + WPP “Maraza” are connected to the system.

On Fig. 1 shows the structure of the parts of the systems - balancing and synchronous, in Fig. 2 shows the probability distribution function of the WPP power forecast error for different values of this power generation, and in Fig. 3, the reserve for power balancing in the energy system of Azerbaijan in the case of installing each individual wind farm at the locations of the WPP "Baku", WPP "Lenkoran" and WPP "Maraza" . Fig. 4 and Fig. 5 show the change in wind speed in the regions of Baku and Maraz.

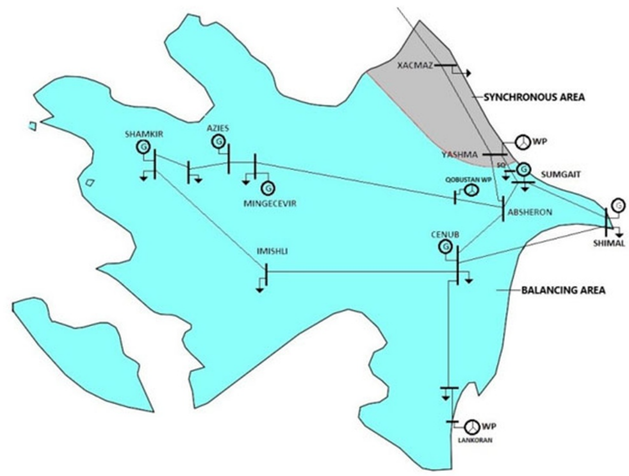

Fig. 1. The structure of parts of systems is balancing and synchronous for Azerenerji

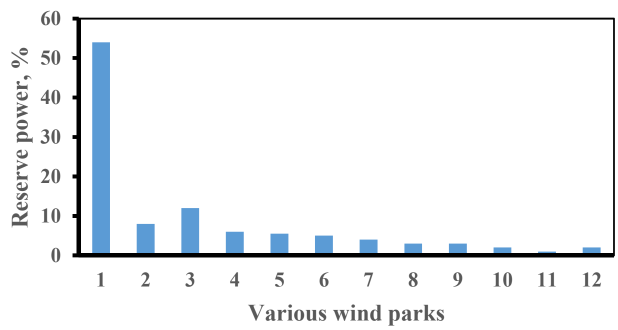

Fig.2. Power Prediction Error Probability Distribution WPP at different values of this power generation

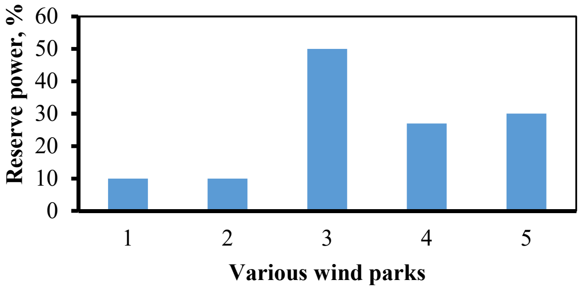

Fig.3. Reserve for power balancing in the energy system of Azerbaijan in cases of installation of each individual wind farm (Baku, Maraza, Lankaran) and their combinations: 1-Lankaran; 2-Maraza; 3-Baku; 4-Baku+Maraza; 5-Baku+Maraza+Lankaran

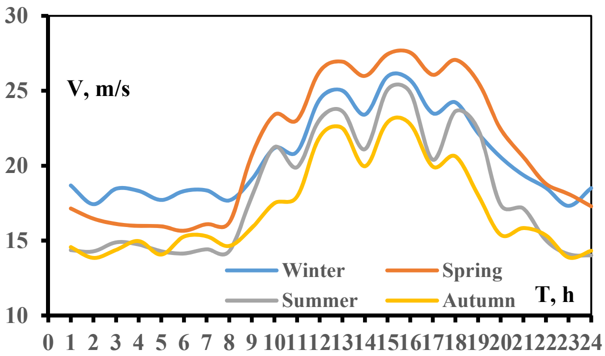

Fig.4. Hourly changes in wind speed in the area of Baku wind farm installation

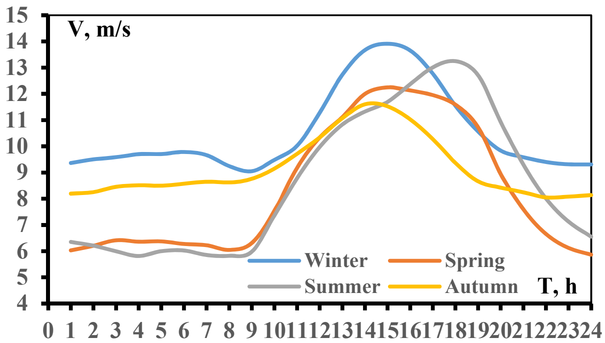

Fig.5. Hourly changes in wind speed in the area of installation of the Maraza wind farm

3 Impact on the statistical stability of RES during power balancing

The need to analyze the impact of RES on the static stability of the energy system of Azerbaijan under the conditions of operational management of the selected value of the balancing power reserve is caused by a large share of the power generated in the system from wind farms (up to 20% of that installed in the system of traditional plants). Long-term observations of climatic conditions show that in a number of regions of Azerbaijan, due to the characteristic features of the dynamics of the energy potential of wind speeds, the electrical energy produced by wind turbines in some periods of time can have a large amplitude. In this paper, to assess the limit of voltage stability in the balancing part of the power system (Fig. 1), at each stage of the implementation of the balance power reserve, the method of sequential mode weighting was applied [6].

Fig. 6 shows the dependence curves $U-P$ for power transmission through a 220 kV power transmission line during the hours of the evening maximum load. The total generation from all wind farms is about 340 MW, which is about 10% of the total system demand. As it was established earlier [3], with the joint operation of three wind farms (wind farms of Baku, Maraza, Lenkoran), the total reserve amounted to about 25% of the installed capacity of wind farms ($\approx 80-85\ MBm$).

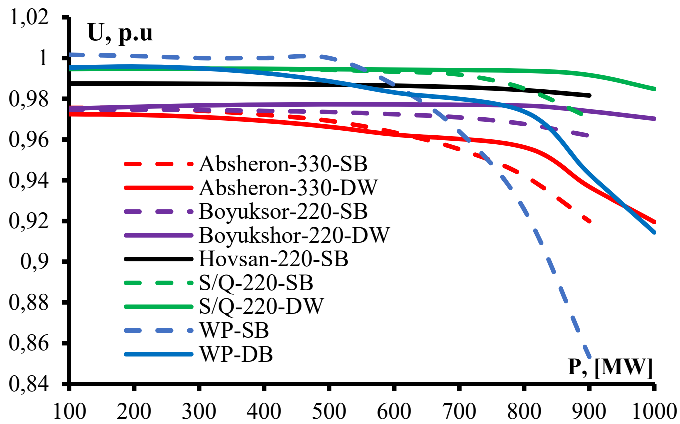

Fig. 6. Power Transfer Curves $U-P$ along power lines 220-330 kV during the hours of the evening maximum load

As can be seen from the curves in Fig. 5, if the total generation from wind farms is reduced by 30-40%, i.e. more than 85 MW, the power reserve will keep the voltage of the controlled power transmission within the allowable critical voltage.

Conclusion

1. The growth of RES integration increases the need for a power reserve to cover the deficit in the balance between supply and demand. The stochastic variability of wind energy sources leads to the need to take into account the influence of the following factors when choosing the reserve capacity to balance: forecast errors in power generation by wind turbines and solar PV installations, the influence of errors in the calculation model of balancing reserves, the influence on the marginal value of the reserve balancing deviation between total generation and consumption .

2. An approach is proposed for estimating the reserve for balancing active power in a system with a dominant

share of RES in the interval of 30-minute stochastic changes in generating capacity from wind turbines; stochastic load changes, random emergency failures of the main objects of the circuit - traditional generators and power lines of the supply network. The proposed approach makes it possible to take into account the dynamics of changes in the balancing power depending on the error in forecasting the discrepancy between the processes of RES generation and power consumption.

3. On the basis of computational and experimental studies in a real power system, it has been established that with an increase in the number of wind farms connected to the backbone circuit in its various nodes, the need for a power reserve can be significantly reduced.

The influence of wind farms of identical capacity in different places of the power system scheme has an unequal effect and the magnitude of the balance power required from their influence can vary significantly.

References

1. IEA (2014a) Advancing variable renewables-grid integration and the economics of flexible power system. International Energy Agency, Paris 2014a, 726 p., https://iea.blob.core.windows.net/assets/e6f58562-203e-474c-97a3-486f409aa7ff/WEO2014.pdf
2. Rakhmanov N.R., Kurbatsky V.G., Guliev H.B., Tomin N.V. *Short-term forecasting of power generation of wind power plants to ensure the reliability of electrical networks,* Proceedings of the International Scientific Seminar. Yu.N.Rudenko "Methodological issues of researching the reliability of large energy systems". Actual problems of reliability of energy systems. Issue 66, Minsk, 2015, pp. 397-404.
3. Rakhmanov N.R., Guliev H.B., Ibragimov F.Sh. *Modeling the generation process of a wind farm when predicting the load power coverage mode in the energy system in intra-daily cycles,* Problems of Energy, No. 3, Baku, 2015, pp. 3-11.
4. Grubb M. *Value of variable sources on power system. IEE,* Pros: Gener. Transm Distib.1991; 138 (2), p. 65-149.
5. 5.UNECE (Renewable Energy Status Report) 2017, pp.98, https://unece.org/DAM/energy/se/pp/renew/Renewable_energy_report_2017_web.pdf
6. 6. Hirth L., Ziegenhagen In. *Balancing power and variable Renewables: Three links,* Renewable and Sustainable Energy Reviews, 50 (2015), p.1035-1051, https://neon.energy/Hirth-Ziegenhagen-2015-Balancing-Power-Variable-Renewables-Links.pdf
7. Guerra K., Haro P., Gutierres R.E., Gomez - Barec . *Facing the high share of variable renewable energy in the Power System: flexibility and stability requirements,* Journal Applied Energy, Elsevier, Vol. 310(C), https://ideas.repec.org/a/eee/appene/v310y2022ics0306261922000460.html
8. European Commission , EG3 Report : *Regulatory recommendations for the development of flexibility*, Smart Grid Force, 2015, pp.93, https://projects2014-2020.interregeurope.eu/fileadmin/user_upload/tx_tevprojects/library/EG3%20Final%20-%20January%202015.pdf
9. Spiegel T. *"Impact of Renewable Energy Expancion to the Balancing Energy Demand of Different Balancing Groups",* Journal of Sustainable Development of Energy, Water and Environment Systems.(2018), Vol. 6., Issue 4 . pp. 784-799
10. Holttinen H., Milligan M., Ela E., Menemenlis N., Dobchinski J., Rawn B., Bessa R.J.,Flynn D., Gomes-Lazaro E., and Detlezsen N.K. *Methodologies to determine operating reserves due to increased wind power*, IEEE Transactions on Sustainable Energy, Vol.3, No. 4, pp. 713-723, 2012
11. Brener C., Engelhartdt C., and Moser A. "*Expectationbased reserve capacity demensioning in power system with an increasing intermittent feed-in",* in 2013 10th International Conference on the European Energy Market (EEM), IEEE ,2013, pp.1-7.
12. Matos M.A., and Bessa R.J., *Setting the operating reserve using probabilistic wing power forecasts,* IEEE Transactions on Power Systems, Vol. 26, Iss. 2, May 2011, p.594-603, https://ieeexplore.ieee.org/document/5565529
13. Cognet, Sylvain, Tracy Wilkison. *Balancing services in Europe.* HIS Cera decision brief ; 2013
14. Rakhmanov N.R., Guliyev H.B. *Application of a neural network model to assess the current value of the voltage stability limit of an electrical system,* Electricity, No. 4,2015, pp. 4-11.
15. Ajjarapu V., and A.Christy C. *The continuation power flow: A tool for steady state voltage stability analysis*, IEEE Transactions on Power Systems , Vol.7., No.1, Feb. 1992, pp. 416-423.
16. Holttinen H. et al. *Design and operation of power system with large amounts of wind power*, Final Resort, IEA wind Task 25, 2006-08, January 2009, Publisher: VTT Tiedotteita - Research Notes 2493, Editor: VTT/Julkaisiga (Ed.), ISBN: 9789513873097