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Stability Operation of Grid Connected Inverter

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Abstract. In the modern electric grid, there is an active penetration of distributed renewable energy sources and energy storage systems, which often require connection by means of electronic converter. Energy sources connected in the grid by means of electronic converter or inverter has large different parameters and operating modes compared to the generation of a traditional one. That leads to a different behavior of such sources in the network. With a large penetration of this kind of generation in the electrical grid, there is a need to revise the principles and methods of design and operation of both inverters and power systems. Otherwise there may be conditions in which it becomes impossible to ensure sustainable power supply and quality of power that satisfy the technical requirements. The goal of the paper is to study the operations of electricity sources connected in the power grid by means of inverter, analyzing the static stability of objects of this kind, as well as studying the possibility of creating algorithms that can successfully adapt such generation objects into a single power system.

1 Introduction

In the modern electric grid, there is an active penetration of distributed renewable energy sources and energy storage systems, which often require connection to the network by means of electronic converter. At the moment, renewable energy sources in Russia are not widely spread yet, but every year the share of distributed renewable energy resources in the electric power system is growing [1-2].

The penetration of solar power plants, energy storage systems and wind generation cause the active spread of electronic converters in the electric power system. Unlike traditional power source at the electrical grid, such as synchronous generator, inverter has significantly different characteristics and principles of operation. Active penetrations of electronic power converters can cause decrease the quality and reliability of power supply [3].

In order to avoid the negative effect associated with the spread of generation connected to the electric grid by means of inverter, it is necessary to study the principles and characteristics of operation. It is also necessary to study the possible problems that may arise as a result of the penetration of converters into the power grid [4-5].

Issues related to static stability of power generation arise when large power plants operate in remote areas. Recently, solar power plants are becoming more and more common in Russia, in the Orenburg region it is planned to build a solar plant with a rate power of 120 MW, in the Altai region it is planned to build about 60 MW of solar generation. At such capacities, will be problems with transmission of electricity to the electric power grid may occur. For this reason, it turns out to be necessary to research the operation in parallel of large generation sources connected to the network via inverter. In this paper, we also studied cases out-of-step operation of the inverter, and suggest possible ways to overcome the problems.

2 The principle of operation of the grid-connected

The principle of operation of converters is based on the shaping of a sinusoidal voltage by switching semiconductor gates, which may be MOSFET or IGBT transistor. The most common way to generate a sinusoidal voltage is pulse-width modulation [6].

The principle of operation of the grid-tie inverter is shown in Figure 1.

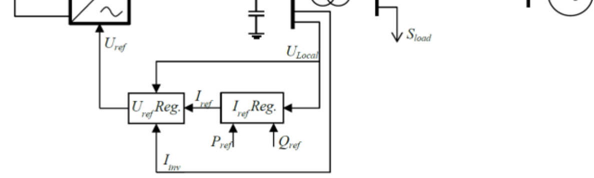

Fig1. Block diagram of the grid-connected inverter

The basic principle of controlling the output active and reactive power is based on the voltage regulation on the inverter buses. The active power is set based on the mode of operation of the electricity source. When a solar power station is connected to the DC buses of the inverter, the output power is calculated using the

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maximum power point search algorithm. Reactive power does not depend on the source of electric energy and can be set depending on the needs of the network [7-8]..

With the network voltage and the setting of the active and reactive power, the required current may be calculated. Between the buses of the electronic converter and the connecting of the inverter to the grid, there is an inductive reactance of the harmonic filter device. Harmonic filter device filters the harmonics current generated as a result of pulse-width modulation. This resistance is the internal resistance of the inverter. For the flow of the calculated current, it is necessary to set the required voltage on the inverter buses, which is defined in dq-coordinates on the basis of equations (1).

$$\begin{aligned} U_d &= U_{d.Local} + I_d \cdot R - I_q \cdot X \\ U_q &= U_{q.Local} + I_d \cdot X + I_q \cdot R \end{aligned} \quad (1)$$

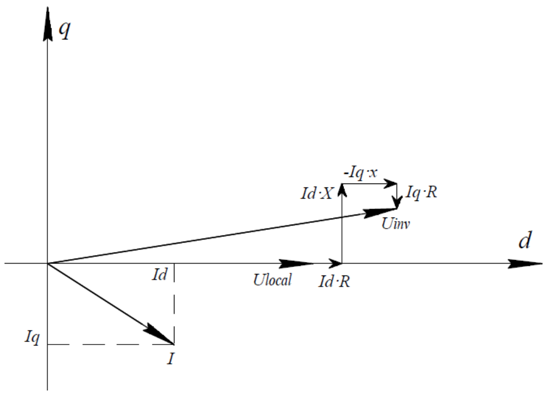

Fig. 2. Vector voltage diagram of the electronic converter

The active resistance of the harmonic filter can be neglected, because it is on order smaller than the inductive reactance. As a result, may be said that the output active power depends directly on the current Id of the inverter, which in turn depends on the angle δ between the grid voltage and the voltage of the inverter. Reactive power depends on the current Iq, which changes as a result of the voltage module regulation on the inverter buses.

3 The stability of the grid-connected inverter

To study the static stability of electronic converters, let us consider a simple power transmission scheme: inverter – transformer – line – power - system. The equivalent circuit of such electricity transmission can be represented by longitudinal inductive resistances (Figure 3).

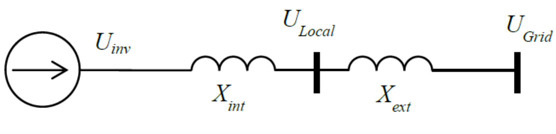

Fig. 3. The equivalent power scheme of the electricity transmission inverter-grid

Having an equivalent resistance, it is possible to obtain the dependence of the active power on the angle δ between the inverter voltage and the system voltage [9-10]:

$$P = \frac{U_{inv} \cdot U_{Grid}}{X_{\Sigma}} \cdot \sin(\delta) \quad (2)$$

Maximum power is reached at δ=90˚. To study the limits static stability of the converter, a model in the software package Matlab Simulink was created. In the experiment, the active power of the inverter gradually increased, as a result the transmission angle increased as expected.

On the one hand, loss of stability of the inverter cannot occur between vectors U_{inv} and U_{Local}, as the electronic converter based on the voltage measured at the U_{Local} output and always operates with its frequency.

On the other hand, out-of-step operation can occur in an electrical system between two voltage vectors at the ends of the power transmission, such as a U_{Local} and a U_{Grid}. In the experiment, with an increase in the transmitted power, at a certain point when it exceeded the maximum, normal power transmission became impossible and converter was out-of-step operation. The results of the research are shown in Figure 4.5.

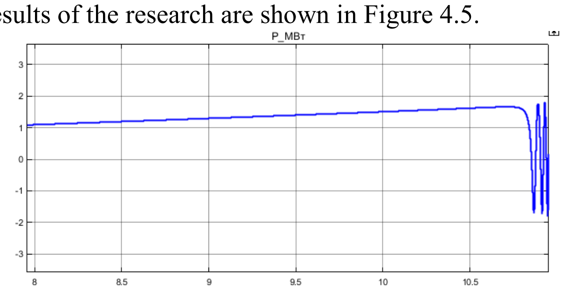

Fig. 4. Graph of changes of the active power of the converter

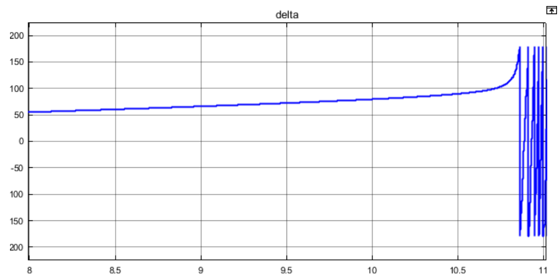

Fig. 5. Graphs of changes the angle δ

4 The criterion for reaching the limit of transmitted power

One of the priority challenges in maintaining modes is to prevent out-of-step operation due to exceeding the limit of transmitted power. Solving the problem of electronic converter into the system can be based on the magnitude of the mutual angle of transmission.

However, for limiting the angle firstly it is necessary to measure the voltage both directly on the inverter buses and on the system buses that can act as infinite buses, and secondly, no specific boundary angle δ_{max}.

This challenge can be solved by relying not on the full angle of power transmission, but on the angle between the voltage vectors on the inverter buses U_{inv} and behind the filter U_{Local}. This angle is directly

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involved in the control of active output power.

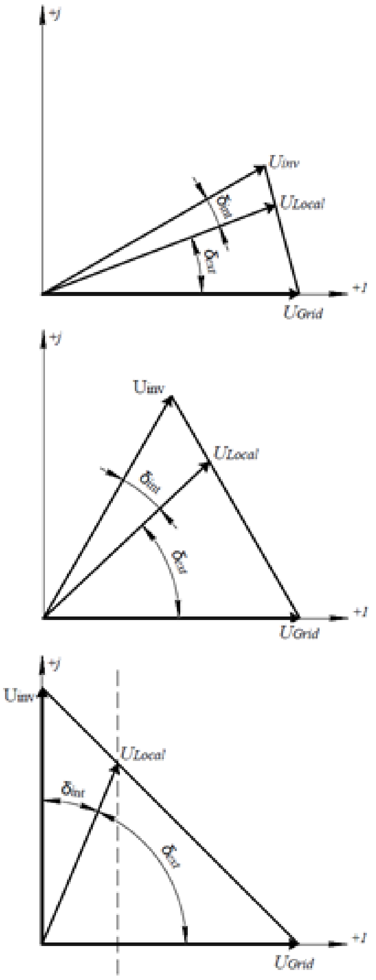

Fig. 6. Vector voltages diagram at different values of the angle δ

Figure 6 shows that the total angle is the sum of the internal angle δ_{int} between the voltage vectors on the inverter buses and behind the filter, and the external angle δ_{ext}, between the voltage vectors behind the filter and the grid voltage. The internal angle at which the limit of the transmitted active power is reached can be determined from the power characteristic $P(\delta_{int})$. Figure 7 shows the dependences of the output active power on the total, internal and external angle

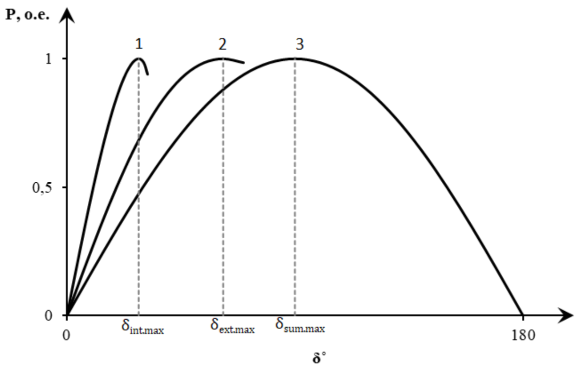

Fig. 7. Characteristic of active power: 1) *P*(*δint*); 2) *P*(*δext*); 3) *P*(*δsum*)

It should be noted that the value of the internal angle at which the limit of transmitted power will be reached depends also on the ratio of internal and external resistance. From Figure 8 it can be seen that the larger the ratio of internal to external resistance, the greater the maximum transmission angle δ_{int} max.

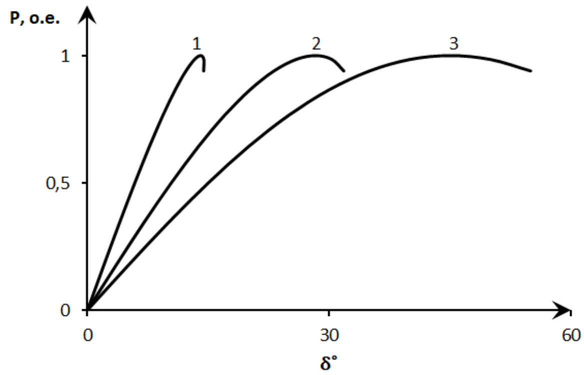

Fig. 8. Characteristic of the active power *P(δint)* with different resistance ratios: 1) with *Xext.> Xint* .; 2) with *Xext.* = *Xint* .; 3) with *Xext*. <*Xint*.

The criterion for reaching the limit of the transmitted power can be δ_{int} max calculated in advance at the computation stage with some margin.

In this case, the standard primary criterion of static stability with ratio of power transmission to the internal angle $dP/(d\delta_{int})$ can also be applied. Obviously, to limit the increase in power output by the inverter is necessary when the derivative tends to zero.

5 Voltage control of the inverter

In addition to controlling active power, the converter can also maintain a constant voltage level directly behind the harmonic filter device, as automatic voltage control of a synchronous generator. In this case, the limit on static stability will be higher. The vector diagram of voltages at different angles is shown in Figure 9.

It can be seen from the figure that with an increase in the active power, the voltage on the U_{inv} inverter buses increases. To ensure normal operation when regulating the voltage on the converter buses, you can set the range of the allowable voltages of the inverter at which stable operation will be ensured.

To figure out a range of the allowable voltages, it is necessary to specify curved lines that unite all possible points of finding the voltage vector U_{inv}, which will ensure the normal operation of the converter.

$$U_{inv}(\delta) = I \cdot jX_{ins} + U_{G.local} = \frac{U_{G.local} - U_{Grid}}{X_{ext}} X_{ins} + U_{G.local} =$$

$$= U_{G.local} + (U_{G.local} - \cos(\delta) \cdot U_{Grid} - j\sin(\delta) \cdot U_{Grid}) \cdot \frac{X_{ins}}{X_{ext}}; \qquad (3)$$

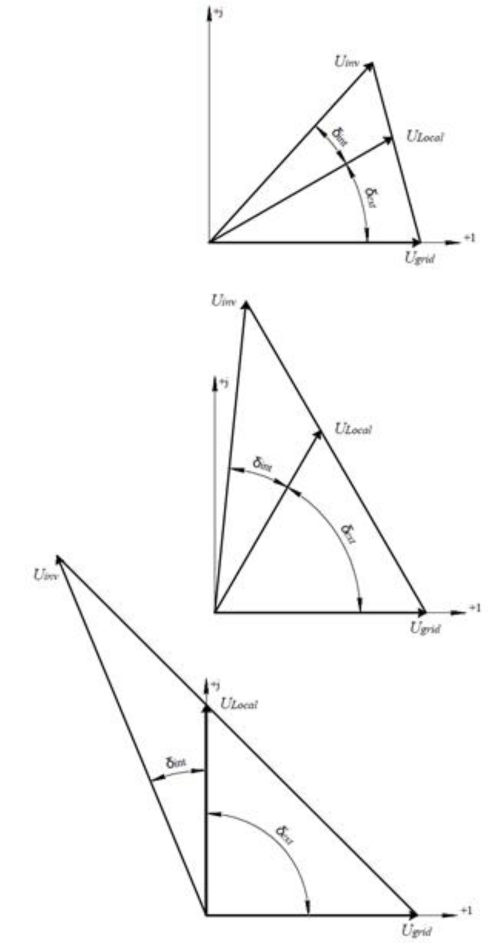

Fig. 9. Vector voltages diagram at different values of the angle *δ*

It is possible define a set of curves, the extremum of which will be the boundaries of the required area by substituting the angle, the required voltage levels on the power plant and the possible mains voltages into Eq. (3). Figure 11 shows the vector diagram, which shows the area of stable operation, also shows the area of maximum voltage that the converter can provide.

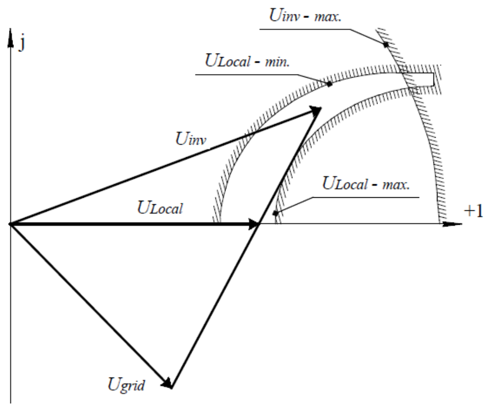

Fig. 10. The range of stable operation of the converter

6 Conclusions

This paper studies the probable causes of the loss of stability of the electronic converters in the power grid. It was found that exceeding the limits on the transmitted power can lead to out-of-step operation.

To prevent loss of the stable operation of the converter, it has been proposed to limit the internal angle of the power transmission, which is directly involved in regulating the output active power. The main criterion for limiting the angle is to achieve the maximum δ_{int}, after which it is necessary to stop increasing the output power to the power grid.

If we consider the existence of a voltage regulator that maintains a constant voltage on the power plant buses, it is necessary to use another criterion to limit the output power. In this case, a possible criterion for determining the point of maximum transmit power is the derivative $dP/d\delta_{int} = 0$.

It is possible to ensure the normal operation of the inverters by setting the range of available operating modes of the converter the voltage vector on the inverter buses, which will take into account the change in the voltage level on the station buses and the power grid voltage.

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