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Ensuring the reliability of voltage and frequency control in modern power grids

Tolipov J.N., Murtazov Sh.I., Tolipov F.N.
Scientific Researchers, Institute of Energy Problems, Academy of Sciences of the Republic of Uzbekistan

Abstract. This article extensively covers the issues of stable and reliable voltage and frequency parameter control in modern power systems. With the widespread use of renewable energy sources in the power sector, such as solar and wind power plants, hybrid systems integrated with traditional centralized power grids are emerging. One of the main problems in such systems is the effective elimination of voltage and frequency disturbances caused by variability in production due to natural factors.

The article notes that photovoltaic panels can cause short-term but significant voltage fluctuations due to rapid changes in light flux. This can reduce the reliability of equipment in the grid and the quality of supply for users. Therefore, it is necessary to implement highly accurate automated control systems in power grids.

Keywords: distributed generation sources, renewable energy sources, power grids, voltage control, frequency stability, reliability index, harmonic distortions, automated control system, electromagnetic compatibility.

Modern power systems are expanding through the integration of renewable energy sources with traditional centralized power grids. One of the main challenges in such a hybrid structure is ensuring the stability of voltage and frequency parameters. The operating mode of renewable sources is highly dependent on natural conditions, and their production capacity often fluctuates. For example, in photovoltaic systems, light flux can change in seconds, which causes short-term voltage dips or surges. In order for centralized power grids to respond to such dynamic changes, it is necessary to implement systems that control voltage and frequency with high accuracy in accordance with IEC standards. Therefore, in order to ensure the reliability of power grids integrated with renewable energy sources, it is required to comply with a number of regulatory and technical requirements.

Voltage and frequency control in power grids is a key element for their reliability and stability. The complexity and distribution of modern power grids require accurate and rapid control of these parameters. Voltage and frequency serve to maintain the balance of energy flows in the grid, as well as ensure the normal operation of equipment in the electrical sector. Violations of these parameters can lead to outages, equipment failures, and economic losses. Therefore, modern technologies and automated control systems are used.

In modern power grids, renewable generation components cause rapid variability in voltage and frequency parameters. For this reason, mathematical modeling tools are used. The main dynamic parameters are evaluated as follows:

Relative voltage deviation:

$$\Delta U = \frac{|U - U_N|}{U_N} 100\%$$

Frequency variation:

$$\Delta f = |f - f_N|$$

Table 1.
Voltage and frequency requirements specified in IEC 61727

Parameter	Value	Limits	Connection/Disconnection Time

Voltage	230 V	±10%	2 s
Frequency	50 Hz	±1 Hz	0,2 s

A reliability index is used to assess the reliability of the control system:

$$R = 1 - \frac{n_{SL}}{N}$$

Where n_{SL} is the number of cases of exceeding the specified limit; N is the total number of measurements during the control period.

If 5 failures are observed in 10,000 inspections, the reliability level is:

$$R = 1 - \frac{5}{10000} = 0{,}9995 = 99{,}95\%$$

This indicator represents high network reliability. As the share of renewable sources increases, the importance of modeling increases.

IEC 61000 standard ensures electromagnetic compatibility and limits harmonic distortions in electrical networks. When renewable energy sources are used, especially when inverters are used, harmonics occur in the voltage. These distortions are evaluated with the total harmonic distortion (THD) coefficient:

$$THD = \sqrt{\sum_{n=2}^{\infty} \left(\frac{U_n}{U_1}\right)^2}\, 100\%$$

According to IEC 61000, the THD value should not exceed 5%. For example, if the share of 3rd, 5th and 7th harmonics is as follows:

U_3=5V, U_5=3V, U_7=2V

The main sinusoidal U_1=230 V,
then:

$$THD = \sqrt{\left(\frac{5}{230}\right)^2 + \left(\frac{3}{230}\right)^2 + \left(\frac{2}{230}\right)^2}\,100\% = 2{,}43\%$$

This is the norm. Filters are used to reduce harmonic distortion. Electromagnetic compatibility and voltage quality are one of the crucial factors in achieving high reliability.

Conclusion

In modern power grids integrated with renewable energy sources, ensuring the stability of voltage and frequency parameters is crucial for maintaining the reliability and quality of power supply. This article analyzes the voltage and frequency dynamics under the influence of renewable generation sources, highlighting the factors that lead to their sharp changes.

In addition, the article extensively covers the possibilities of real-time monitoring through automated control systems, filtering technologies, and reliability indices. It should be noted that this approach not only ensures the stability of power grids but also contributes to the effective integration of renewable sources. Therefore, in the process of widespread introduction of renewable energy sources in electric power systems, scientific and practical research and technological solutions aimed at controlling the voltage and frequency parameters of electric grids with high accuracy should be considered a priority.

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