INFLUENCE OF NON-SINUSOIDALITY OF VOLTAGE ON ELECTRICITY LOSS IN DISTRIBUTION NETWORKS

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Abstract. The problem of electromagnetic compatibility in high-voltage distribution networks is considered, connected with the consumption of reactive power at the fundamental frequency and distortion of the current form in the feeding networks. The estimated indices of the calculation of power losses for non-sinusoidal supply voltage in the high-voltage distribution network for the PNS pump with a capacity of 50 MW are given. Methods for reducing the voltage non-sinusoidality.

Powerful dynamic superchargers of a megawatt class are the basis of gas-oil pumping stations of main pipe-wires. The energy efficiency, reliability and environmental compatibility of the pipeline systems largely depend on the energy characteristics of the dynamic superchargers. At present, there is a steady trend towards the use of high-voltage frequency converters for regulated electric drives of dynamic superchargers. Being a non-linear load for a high-voltage distribution network, frequency converters distort the shape of the current in the supply line and thereby cause distortion of the supply voltage, which adversely affects other electrical receivers.

The problem of electromagnetic compatibility (EMC) in high-voltage distribution networks is associated with the consumption of reactive power at the fundamental frequency and distortion of the current form in the supply networks. At the same time, generating higher harmonics of current cause additional losses of electricity, heating insulation and other negative effects.

Pumping of oil through main pipelines is carried out in accordance with the technological chain (Figure 1).

![Figure 1. Technological process of oil transfer through the main pipeline: F - receiving filters; P - the distributor; RP - tank farm; PNS - retaining pumping station; MNA - main pump unit; DZ - throttling gate; LU - linear section of the main pipeline.](image)

At the moment, mainly centrifugal pumps are used with drive high-voltage asynchronous motors with a squirrel-cage rotor. The installed power of one engine lies in the range from 3000 kW to 10,000 kW. Two methods are used to control the pressure and supply of oil: by controlling the damper at the pump outlet and by changing the rotor speed of the pump. The second method is the most energy efficient and can be
used not only to regulate the rotor speed of the pump, but also to make the motor run smoothly, especially when the pump is running in a long-running nominal mode.

In Fig. 2 shows a fragment of the scheme of power supply of pump units with adjustable electric drives based on the frequency converter - asynchronous motor. It follows from Fig. 2, each pump can work when the motor is directly connected to a high-voltage network or through a thyristor high-voltage frequency converter that performs a soft start or regulates the rotational speed of the rotor of one of the pumps.

The higher harmonic components of voltages and currents in power supply systems cause additional losses of electrical energy in the supply lines, transformers [1, 2].

Calculation of power losses in power lines is made by the formula (1):

\[
\Delta P_{2n} = 3 \sum_{n=2}^{p} I_{n}^2 \cdot R_{1} \cdot k_{rn},
\]

where \( n \) is the number of the harmonic; \( p \) is the number of harmonics taken into account; \( I_{n} \) is the current of the \( n \)th harmonic; \( R_{1} \) is the line resistance at the fundamental frequency; \( k_{rn} \) is a coefficient that takes into account the effect of the surface effect.

![Figure 2. Scheme of power supply of pumping units of PNS](image)

Calculation of power losses in the transformer is made by the formula (2):

\[
\Delta P_{2n} = 3 \sum_{n=2}^{p} I_{n}^2 \cdot R_{k1} \cdot k_{mn},
\]

where \( R_{k1} \) is the short-circuit impedance of the transformer at the fundamental frequency; \( k_{mn} \) is a coefficient that takes into account the increase in the short-circuit resistance for higher harmonics due to the effect of the surface effect and the proximity effect.

Preliminary calculations for a fragment of the power supply scheme show a significant influence of higher harmonics on the energy losses in distribution networks. The results of calculating the losses of power and electricity [4] in about eight hours of operation of one pump with a power of 5000 kW are presented in Table 1.

| Losses in transmission lines | 1500 | 1100 | 1020 | 1350 | 1080 | 980 | 1320 | 1150 |
|-----------------------------|------|------|------|------|------|-----|------|------|

Table 1. Estimated values for calculating power losses for non-sinusoidal supply voltage in the high-voltage distribution network \( \Delta P \), W, for the PNS pump, engine power 50 MW
The total additional power losses in the elements of the power supply system from non-sinusoidal power amounted to \( \Delta P_{\Sigma_{n_{tot}}} = 58.3 \text{ kW} \), and the total additional power losses for seven hours amounted to \( \Delta W_{\Sigma_{tot}} = 466.4 \text{ kW·h} \).

To reduce the voltage nonsinusoidality, it is possible by the following methods, which are divided into three groups:
- the scheme method: non-linear loads are allocated to a separate bus system; the location of this type of load on various nodes in the power supply system; grouping of converters according to the scheme of phase multiplication; connection of the load to a system with a power greater than that of a linear one;
- the use of narrow-band resonant filters, including their parallel load, as well as the inclusion of filtering, filtering, and active longitudinal and transverse inclusion filters;
- the use of equipment that have improved energy indicators: "non-saturated" transformers, multiphase transducers.

It should be noted that the methods of compensation are not universal: the choice of method depends on a number of factors [5]:
- level of generated harmonics, determined by the type of the source of higher harmonics (arc furnace, welding installations);
- the position of the source in the circuit and the power flows at the connection point and its effect on other electrical receivers installed in electrical proximity;
- availability of compensation means in the scheme
- frequency characteristics of electricity supply, as well as the probability of occurrence of resonance at the generated frequencies by a source of harmonics.

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References
[1] Zukhairy A., Vinogradov A 2014 The status of the issue of use (SMART GRID) vol 3 APRIORI Series: natural and technical sciences
[2] Averbukh M, Prasol D, Khvorostenko S 2017 Experimental estimation of parameters of regimes in high-voltage mine networks with powerful non-linear electric receivers vol 2Vestnik of Irkutsk State Technical University pp 75-84
[3] Dolinger S, Lyutarevich A, Goryunov V 2013 Estimation of additional power losses due to a decrease in the quality of electrical energy in the elements of the power supply system vol 2Omsk Scientific Bulletin pp 178-183
[4] Kartashev I, Tulsky V, Chamonov R (Electricity quality management vol 3)ed Sharov Yu. (Publishing house MPEI) p 347
[5] Averbukh M, Kuznetsov V, Korzhov D2013Problems of ensuring electromagnetic compatibility in electrical installations of industrial enterprises Bulletin of Belgorod State Technological University named after V G Shukhov vol 5 pp 203-207