Analysis of resonance modes at harmonic frequencies in high-voltage networks

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Methodical approach for detecting nodes with resonant mode and resonant harmonics

Mathematical model of the network mode at the *h*-th harmonic

$$U_h = Z_h I_h, \text{ where } Z_h = Y_h^{-1}.$$

To detect the resonance mode in the *i*-th node, the following parameters are used: $K_{U(h)}$ - the *h*-th harmonic factor; K_L - limit values for $K_{U(h)}$; $I_{h,I}$ - current value of the *h*-th harmonics in the *i*-th node; $y_{h,i} = 1/z_{h,i}$, $g_{h,i} = r_{h,i}/z_{h,i}$, $b_{h,i} = x_{h,i}/z_{h,i}$ - admittance, conductance and susceptance of network node. HARMONICS software is designed to calculate these parameters.

Conditions for detecting nodes and harmonics of the resonant mode:

1. First, nodes where $K_{U(h)} > K_L$ are checked:

1) high current value $I_{h,I}$;

2) the susceptance of the node at the *h*-th harmonic is zero, or its sign changes at the *(h+1)*-th harmonic;
the sign of the susceptance changes from minus to plus in series resonance, and from plus to minus in parallel resonance;

3) the values of conductance and admittance are close, and the value of susceptance, as a rule, is one order of magnitude less than the values of conductance and admittance;

2. then, nodes where $K_{U(h)} < K_L$ are checked: the small values of susceptance comparing with conductance and admittance; the sign change from minus to plus, and from plus to minus.

Examples of resonance modes on harmonics in networks of Eastern Siberia

Resonance modes at the 220 kV Pokosnoe substation (node 2401)

Table I. - Parameters of the node and mode

h	$K_{U(h)}$ (%)	K_L (%)	y_h (S)	g_h (S)	b_h (S)	I_h (A)
3	0.98	1.50	0.0066	0.0009	-0.0065	21.31
5	1.15	1.50	0.0028	0.0005	-0.0028	10.68
7	**1.67**	1.00	0.0020	0.0015	-0.0013	7.29
9	**0.69**	0.40	0.0045	0.0037	-0.0026	2.78
11	**1.22**	1.00	0.0027	0.0024	0.0013	7.38
13	**1.72**	0.70	0.0036	0.0036	-0.0001	9.68
17	0.18	0.50	0.0126	0.0085	0.0092	2.47
19	0.22	0.40	0.0235	0.0234	-0.0008	4.60
23	0.23	0.40	0.0142	0.0112	-0.0087	2.91
25	0.13	0.40	0.0069	0.0057	-0.0038	0.78

The table shows that susceptance has a negative sign at the 9-th harmonic and a positive sign at the 11-th harmonic, which indicates a series resonance. Admittance and conductance of the 11-th harmonic have alike values, i.e. resonance is possible. The susceptance changes the sign. This implies that on the 13-th harmonic the mode is close to the resonant mode. The change in the susceptance sign at the interval of the 13-17-th harmonics means there is series resonance. Between the 17 and 19-th harmonics one can observe the change of the sign which shows parallel resonance.

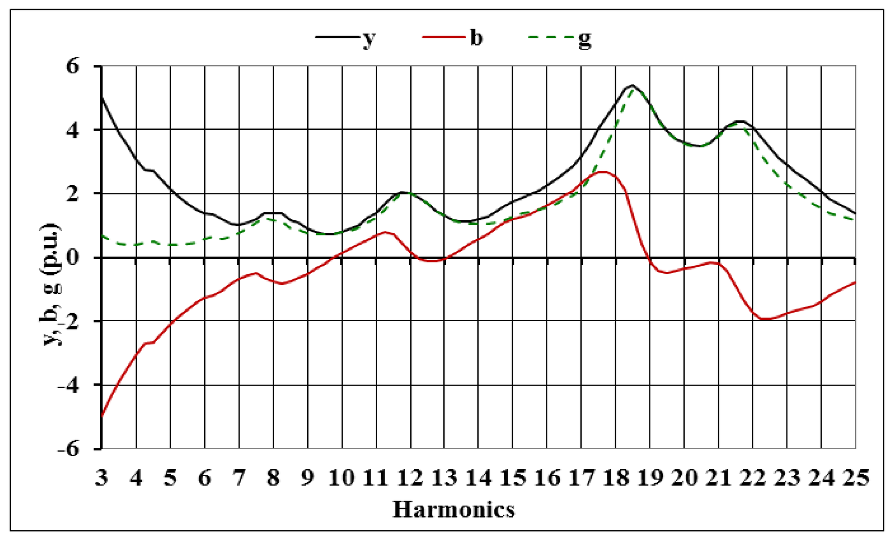

Fig. 1. Frequency responses on the 3-25-th harmonics in the node 2401

Figure 1 shows that in the network in relation to the analyzed node on the harmonic from 9-th to 19-th there are four resonances: two series and two parallel

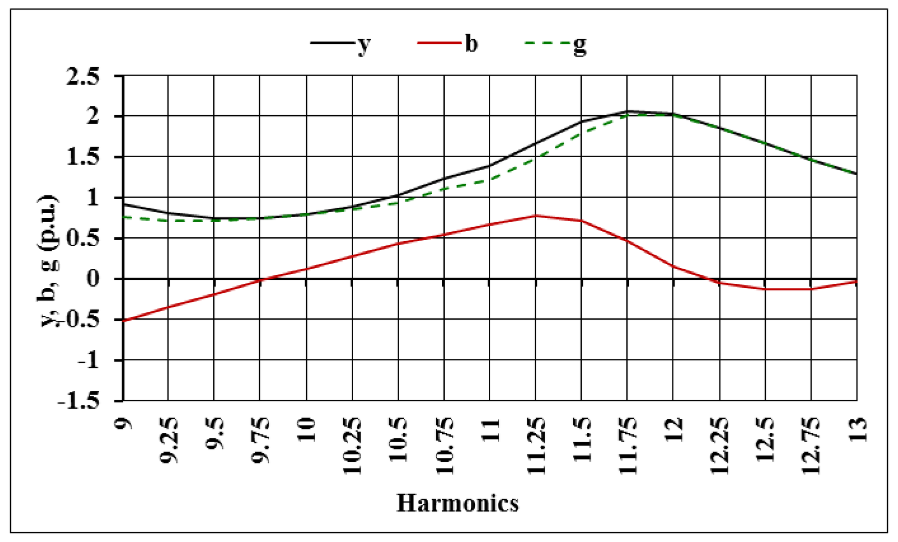

Fig. 2. Frequency responses on the 9-13-th harmonics in the node 2401

Figure 2 shows that the first resonance occurs on the harmonic 9.8, the second occurs on the harmonic 12.2, the third resonance is observed on the 13-th harmonic.

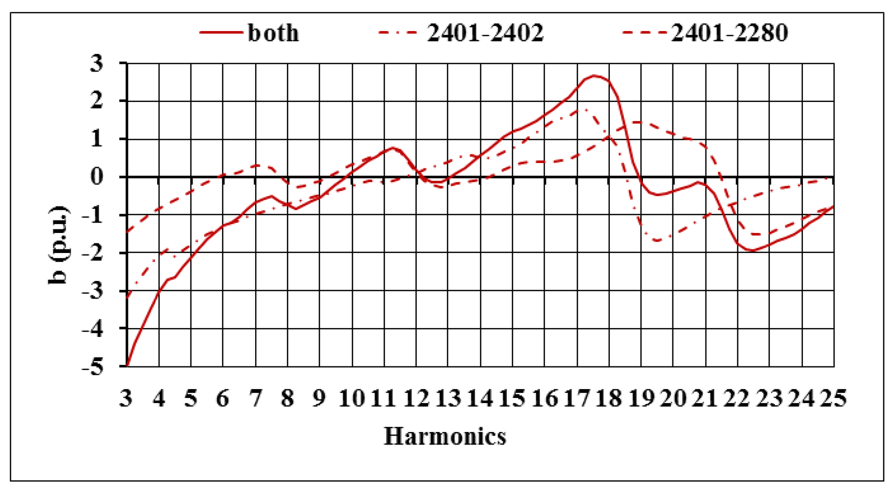

Fig. 3. Frequency response of susceptance for node 2401

Two 220 kV lines are connected to the node 2401: 2401-2280 and 2401-2402. Figures 3 shows the frequency responses of the susceptance for three cases: both lines are turned on; the line 2401-2402 is turned off; the line 2401-2280 is turned off.

Resonance modes at the 110 kVTaksimo substation

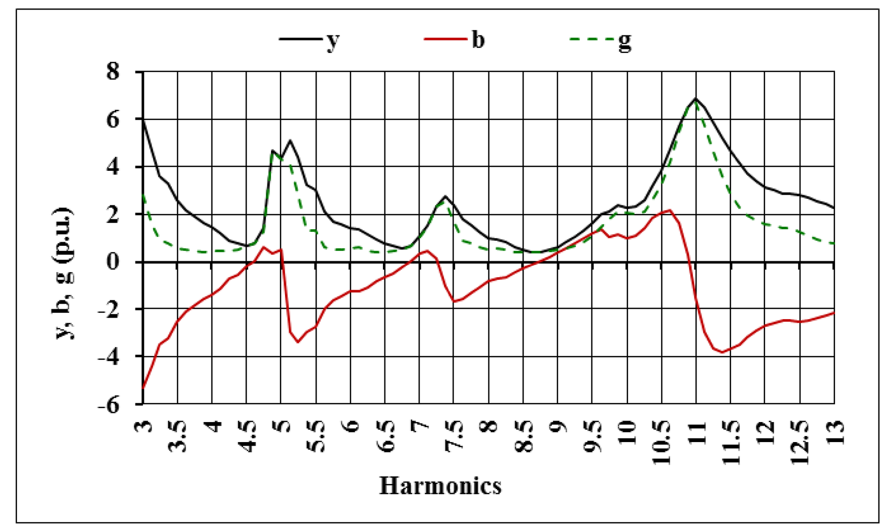

Fig. 4. Frequency responses on the 3-13-th harmonics

Figure 4 shows series resonances at harmonics 4.5, 6.6 and 8.5 and parallel resonances at harmonics 4.9, 7.1 and 10.9, which are called interharmonics.

Resonance modes in the 220kV network

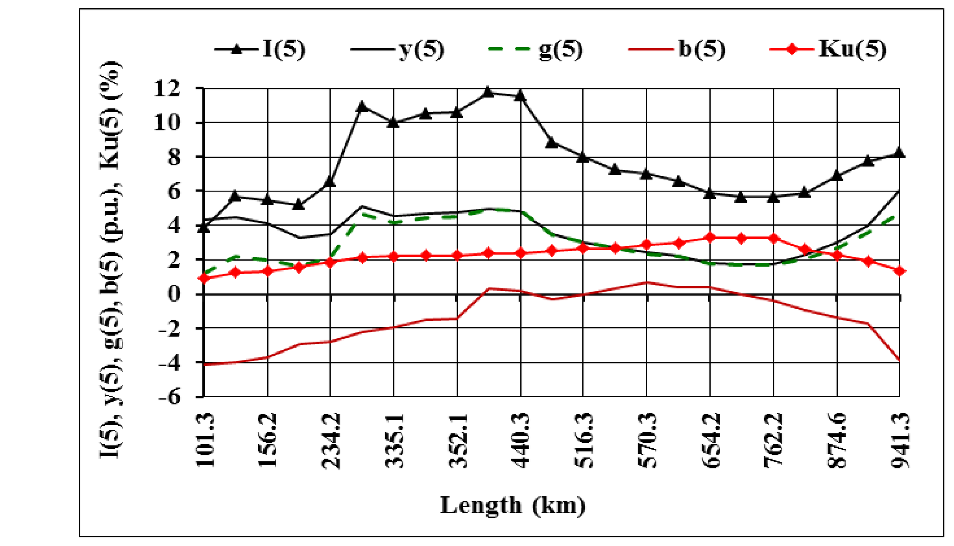

Fig. 5. Parameters of nodes and modes of 220 kV network on the 5-th harmonic

Figure 5 shows that resonance modes occur on the interval from 400 to 700 km. Susceptance changes its sign four times. Two series resonances and two parallel resonances occur on the 5-th harmonic.

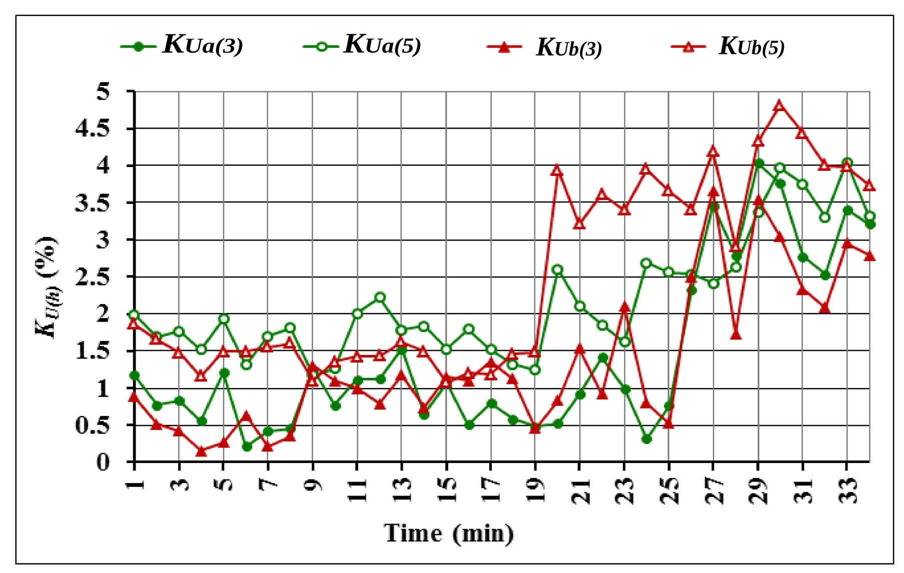

Fig. 6. $K_{U(h)}$ at the Tataurovo substation

Figure 6 shows $K_{U(h)}$ measured in phases B and C at the Tataurovo substation before and after turning on the capacitor bank. The capacitor bank was turned on the 19-th minute.

CONCLUSION

1. Resonance modes in electrical networks occur randomly by various changes in the network configuration and load powers, as well as turning on capacitor banks and passive harmonic filters. Resonance modes are one of the reasons for the high values of voltage and current harmonics.

2. Resonant circuits and modes in high voltage electrical networks can be determined and analyzed using special software. Special software can be used in the operation of electric networks for predicting resonance modes at various harmonics during power quality control.