ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ АВТОНОМНОЕ
ОБРАЗОВАТЕЛЬНОЕ УЧРЕЖДЕНИЕ ВЫСШЕГО ОБРАЗОВАНИЯ
«НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ УНИВЕРСИТЕТ
«ВЫСШАЯ ШКОЛА ЭКОНОМИКИ»

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КУРС: ТЕОРИЯ ЭЛЕКТРИЧЕСКИХ ЦЕПЕЙ

ДОМАШНЕЕ ЗАДАНИЕ №4

«ДЛИННЫЕ ЛИНИИ»

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Вариант 6

Москва
2021

Входные данные:

$R_0 = 25 * 10^3$ Ом/м
$L_0 = 25 * 10^{-6}$ Гн/м
$C_0 = 2 * 10^{-9}$ Ф/м
$g_0 = 1$ См/м
$f = 1 * 10^9$ Гц
$d = 1 * 10^{-3}$ м
$n = 10$

Комплексные сопротивление и проводимость

$$Z_0 = R_0 + j\omega L_0 = 25 * 10^3 + j * 2 * 3.1415926 * 1 * 10^9 * 25 * 10^{-6} = (25 + j157.070) * 10^3 \frac{\text{Ом}}{\text{м}}$$

$$Y_0 = g_0 + j\omega C_0 = 1 + j * 2 * 3.1415926 * 1 * 10^9 * 2 * 10^{-9} = 1 + j12.566 \frac{\text{См}}{\text{м}}$$

$$Z_C = \sqrt{\frac{Z_0}{Y_0}} = \sqrt{\frac{(25 + j157.070) * 10^3}{1 + j12.566}} \approx 112.239 - j4.404$$

$$\gamma = \sqrt{Z_0 Y_0} = \sqrt{\left((25 + j157.070) * 10^3\right) * (1 + j12.566)} \approx 167.575 + j1405.995 = \alpha + j\beta$$

Сопротивление имеет емкостной характер, т.к. $Im(Z_C) < 0$

$$C_C = \frac{1}{2 * 3.1415926 * 1 * 10^9 * 4.404} \approx 36.139 * 10^{-12} \text{ Ом}$$

$$V = \frac{\omega}{\beta} = \frac{2 * 3.1415926 * 1 * 10^9}{1405.995} \approx 4.469 * 10^6 \text{ м/с}$$

$$\lambda = \frac{2\pi}{\beta} = \frac{2 * 3.1415926}{1405.995} \approx 4.469 * 10^{-3} \text{ м}$$

Параметры секции:

$$R_M = \frac{R_0 d}{n} = \frac{25 * 10^3 * 1 * 10^{-3}}{10} = 2.5 \text{ Ом}$$

$$L_M = \frac{L_0 d}{n} = \frac{25 * 10^{-6} * 1 * 10^{-3}}{10} = 2.5 * 10^{-9} \text{ Гн}$$

$$C_M = \frac{C_0 d}{n} = \frac{2 * 10^{-9} * 1 * 10^{-3}}{10} = 0.2 * 10^{-12} \text{ Ф}$$

$$g_M = \frac{g_0 d}{n} = \frac{1 * 1 * 10^{-3}}{10} = 10^{-4} \text{ См}$$

$$R_g = \frac{1}{g_M} = 10^4 \text{ Ом}$$

cir-файлы и скрины вывода спайса для разных пунктов задания ниже. cir-файлы отличаются друг от друга только в RL и CL строках. Графики в самом конце.

7. Согласованая нагрузка

```
V 1 0 AC=1V
R1 1 2 1n
R2 3 4 1n
R3 5 6 1n
R4 7 8 1n
R5 9 10 1n
R6 11 12 1n
R7 13 14 1n
R8 15 16 1n
R9 17 18 1n
R10 19 20 1n
RL 21 22 112.2
CL 22 0 36.1p
X1 2 0 3 TLINE
X2 4 0 5 TLINE
X3 6 0 7 TLINE
X4 8 0 9 TLINE
X5 10 0 11 TLINE
X6 12 0 13 TLINE
X7 14 0 15 TLINE
X8 16 0 17 TLINE
X9 18 0 19 TLINE
X10 20 0 21 TLINE
.subckt TLINE 1 2 6
R 1 3 1.25
R1 4 5 1.25
L 3 4 1.25n
L1 5 6 1.25n
```

Rg 4 2 10k

C 4 2 200f

.ends

.AC LIN 1 1g 1g

.PRINT AC I(R1) I(R2) I(R3) I(R4) I(R5) I(R6) I(R7) I(R8) I(R9) I(R10) I(RL)

.PRINT AC V(2) V(4) V(6) V(8) V(10) V(12) V(14) V(16) V(18) V(20) V(21)

7. Согласованая нагрузка

```
       --- AC Analysis ---

frequency:     1e+009         Hz
V(2):          mag:           1 phase: -1.98494e-011°       voltage
V(4):          mag:     0.98335 phase:   -8.07519°          voltage
V(6):          mag:     0.96704 phase:   -16.1499°          voltage
V(8):          mag:    0.951057 phase:   -24.2233°          voltage
V(10):         mag:    0.935389 phase:   -32.2944°          voltage
V(12):         mag:    0.920017 phase:   -40.3622°          voltage
V(14):         mag:     0.90492 phase:    -48.426°          voltage
V(16):         mag:    0.890075 phase:   -56.4855°          voltage
V(18):         mag:    0.875459 phase:   -64.5406°          voltage
V(20):         mag:     0.86105 phase:   -72.5917°          voltage
V(21):         mag:    0.846828 phase:   -80.6395°          voltage
I(Rl):         mag: 0.00754166 phase:   -78.3893°          device_current
I(R10):        mag: 0.00767053 phase:   -70.3118°          device_current
I(R9):         mag: 0.00780212 phase:   -62.2382°          device_current
I(R8):         mag: 0.00793631 phase:   -54.1684°          device_current
I(R7):         mag:  0.0080731 phase:   -46.1027°          device_current
I(R6):         mag: 0.00821217 phase:   -38.0416°          device_current
I(R5):         mag: 0.00835333 phase:   -29.9846°          device_current
I(R4):         mag: 0.00849642 phase:   -21.9308°          device_current
I(R3):         mag: 0.00864158 phase:   -13.8788°          device_current
I(R2):         mag: 0.00878877 phase:   -5.82831°          device_current
I(R1):         mag: 0.00893802 phase:    2.22139°          device_current
```

8. Холостой ход

```
V 1 0 AC=1V
R1 1 2 1n
R2 3 4 1n
R3 5 6 1n
R4 7 8 1n
R5 9 10 1n
R6 11 12 1n
R7 13 14 1n
R8 15 16 1n
R9 17 18 1n
R10 19 20 1n
RL 21 0 1G
*CL 22 0 12.2p
X1 2 0 3 TLINE
X2 4 0 5 TLINE
X3 6 0 7 TLINE
X4 8 0 9 TLINE
X5 10 0 11 TLINE
X6 12 0 13 TLINE
X7 14 0 15 TLINE
X8 16 0 17 TLINE
X9 18 0 19 TLINE
X10 20 0 21 TLINE
.subckt TLINE 1 2 6
R 1 3 1.25
R1 4 5 1.25
L 3 4 1.25n
L1 5 6 1.25n
```

Rg 4 2 10k

C 4 2 200f

.ends

.AC LIN 1 1g 1g

.PRINT AC I(R1) I(R2) I(R3) I(R4) I(R5) I(R6) I(R7) I(R8) I(R9) I(R10) I(RL)

.PRINT AC V(2) V(4) V(6) V(8) V(10) V(12) V(14) V(16) V(18) V(20) V(21)

8. Холостой ход

```
       --- AC Analysis ---

frequency:     1e+009         Hz
V(2):          mag:           1 phase: -1.55329e-009°       voltage
V(4):          mag:     1.43182 phase:    -19.6976°          voltage
V(6):          mag:     1.92283 phase:     -29.589°          voltage
V(8):          mag:     2.40933 phase:    -35.2318°          voltage
V(10):         mag:      2.8637 phase:    -38.7896°          voltage
V(12):         mag:     3.26974 phase:    -41.1736°          voltage
V(14):         mag:     3.61602 phase:    -42.8169°          voltage
V(16):         mag:     3.89393 phase:     -43.946°          voltage
V(18):         mag:     4.09699 phase:    -44.6858°          voltage
V(20):         mag:     4.22065 phase:    -45.1059°          voltage
V(21):         mag:     4.26217 phase:    -45.2423°          voltage
I(Rl):         mag: 4.26217e-009 phase:    -45.2423°        device_current
I(R10):        mag: 0.00537276 phase:     40.2124°          device_current
I(R9):         mag:  0.0106411 phase:     40.3435°          device_current
I(R8):         mag:  0.0157019 phase:     40.5726°          device_current
I(R7):         mag:  0.0204575 phase:     40.9025°          device_current
I(R6):         mag:  0.0248153 phase:      41.331°          device_current
I(R5):         mag:  0.0286908 phase:     41.8708°          device_current
I(R4):         mag:  0.0320109 phase:     42.5318°          device_current
I(R3):         mag:  0.0347123 phase:     43.3273°          device_current
I(R2):         mag:  0.0367451 phase:     44.2755°          device_current
I(R1):         mag:   0.038074 phase:     45.4005°          device_current
```

9. Короткое замыкание

V 1 0 AC=1V

R1 1 2 1n

R2 3 4 1n

R3 5 6 1n

R4 7 8 1n

R5 9 10 1n

R6 11 12 1n

R7 13 14 1n

R8 15 16 1n

R9 17 18 1n

R10 19 20 1n

RL 21 0 1n

*CL 22 0 12.2p

X1 2 0 3 TLINE

X2 4 0 5 TLINE

X3 6 0 7 TLINE

X4 8 0 9 TLINE

X5 10 0 11 TLINE

X6 12 0 13 TLINE

X7 14 0 15 TLINE

X8 16 0 17 TLINE

X9 18 0 19 TLINE

X10 20 0 21 TLINE

.subckt TLINE 1 2 6

R 1 3 1.25

R1 4 5 1.25

L 3 4 1.25n

L1 5 6 1.25n

Rg 4 2 10k

C 4 2 200f

.ends

.AC LIN 1 1g 1g

.PRINT AC I(R1) I(R2) I(R3) I(R4) I(R5) I(R6) I(R7) I(R8) I(R9) I(R10) I(RL)

.PRINT AC V(2) V(4) V(6) V(8) V(10) V(12) V(14) V(16) V(18) V(20) V(21)

9. Короткое замыкание

```
       --- AC Analysis ---

frequency:     1e+009         Hz
V(2):          mag:           1 phase: 7.85728e-011°       voltage
V(4):          mag:    0.965098 phase:   -1.12475°         voltage
V(6):          mag:    0.911705 phase:   -2.07243°         voltage
V(8):          mag:    0.840757 phase:   -2.86743°         voltage
V(10):         mag:     0.75356 phase:    -3.5279°         voltage
V(12):         mag:    0.651762 phase:   -4.06755°         voltage
V(14):         mag:    0.537311 phase:   -4.49693°         voltage
V(16):         mag:    0.412412 phase:    -4.8237°         voltage
V(18):         mag:    0.279486 phase:   -5.05345°         voltage
V(20):         mag:    0.141118 phase:   -5.18987°         voltage
V(21):         mag: 8.91544e-012 phase:   -86.2076°        voltage
I(Rl):         mag: 0.00891544 phase:   -86.2076°          device_current
I(R10):        mag: 0.00882859 phase:   -86.0712°          device_current
I(R9):         mag: 0.00856993 phase:    -85.651°          device_current
I(R8):         mag: 0.00814517 phase:   -84.9116°          device_current
I(R7):         mag: 0.00756383 phase:   -83.7838°          device_current
I(R6):         mag: 0.00683947 phase:   -82.1406°          device_current
I(R5):         mag: 0.00599011 phase:   -79.7573°          device_current
I(R4):         mag: 0.00503966 phase:   -76.1997°          device_current
I(R3):         mag: 0.00402198 phase:   -70.5583°          device_current
I(R2):         mag: 0.00299489 phase:   -60.6668°          device_current
I(R1):         mag: 0.00209151 phase:   -40.9709°          device_current
```

10. Активная нагрузка

```
V 1 0 AC=1V
R1 1 2 1n
R2 3 4 1n
R3 5 6 1n
R4 7 8 1n
R5 9 10 1n
R6 11 12 1n
R7 13 14 1n
R8 15 16 1n
R9 17 18 1n
R10 19 20 1n
RL 21 0 224.5
*CL 22 0 12.2p
X1 2 0 3 TLINE
X2 4 0 5 TLINE
X3 6 0 7 TLINE
X4 8 0 9 TLINE
X5 10 0 11 TLINE
X6 12 0 13 TLINE
X7 14 0 15 TLINE
X8 16 0 17 TLINE
X9 18 0 19 TLINE
X10 20 0 21 TLINE
.subckt TLINE 1 2 6
R 1 3 1.25
R1 4 5 1.25
L 3 4 1.25n
L1 5 6 1.25n
```

Rg 4 2 10k

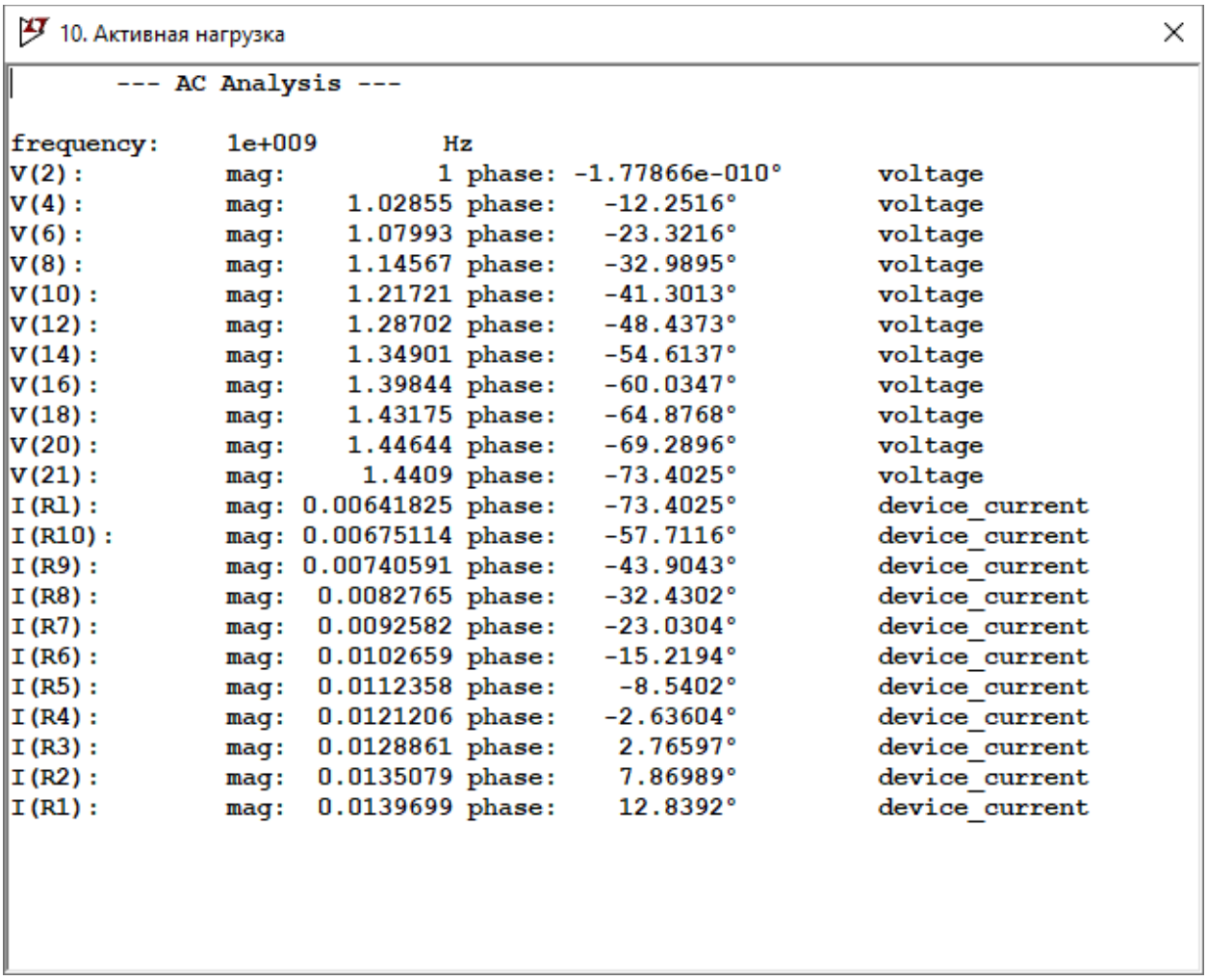
C 4 2 200f

.ends

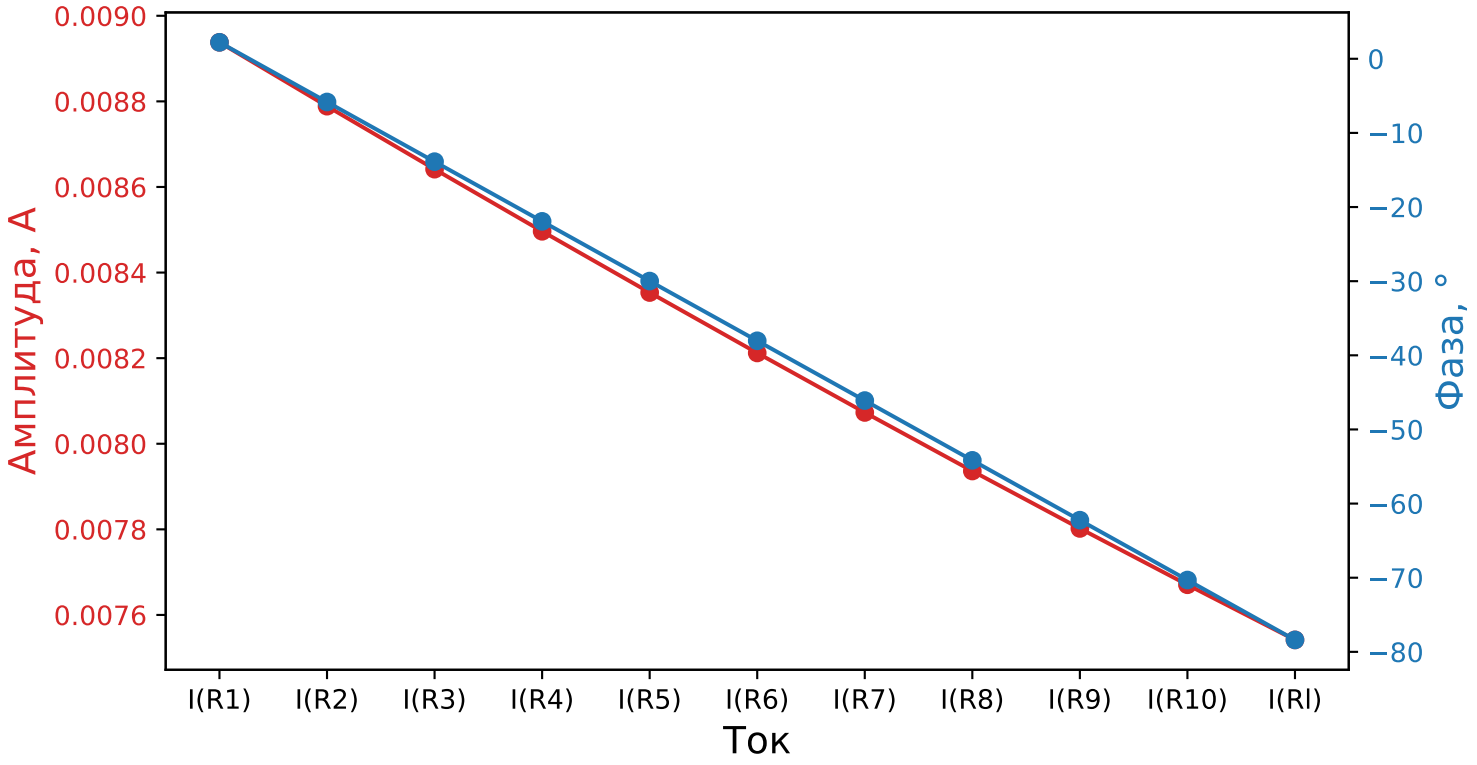
.AC LIN 1 1g 1g

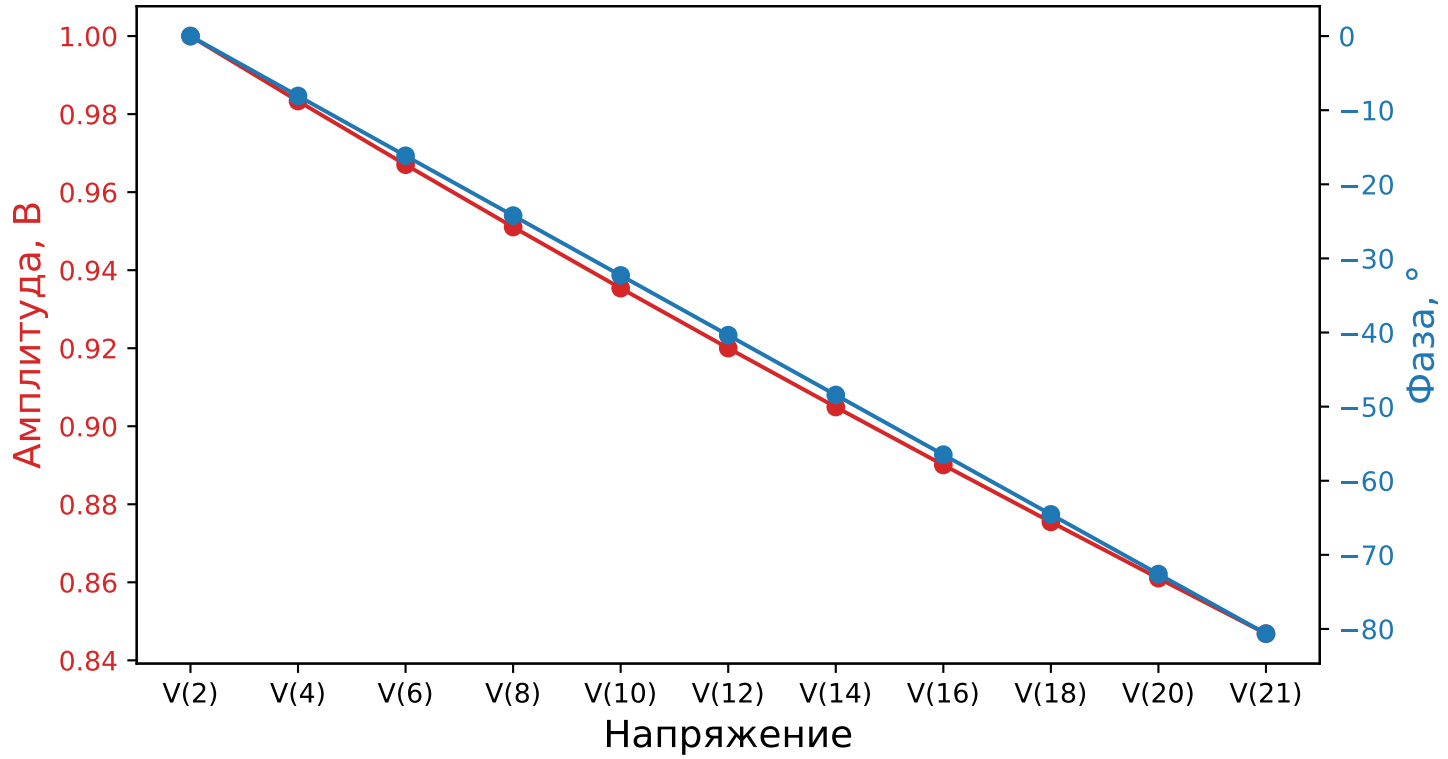
.PRINT AC I(R1) I(R2) I(R3) I(R4) I(R5) I(R6) I(R7) I(R8) I(R9) I(R10) I(RL)

.PRINT AC V(2) V(4) V(6) V(8) V(10) V(12) V(14) V(16) V(18) V(20) V(21)

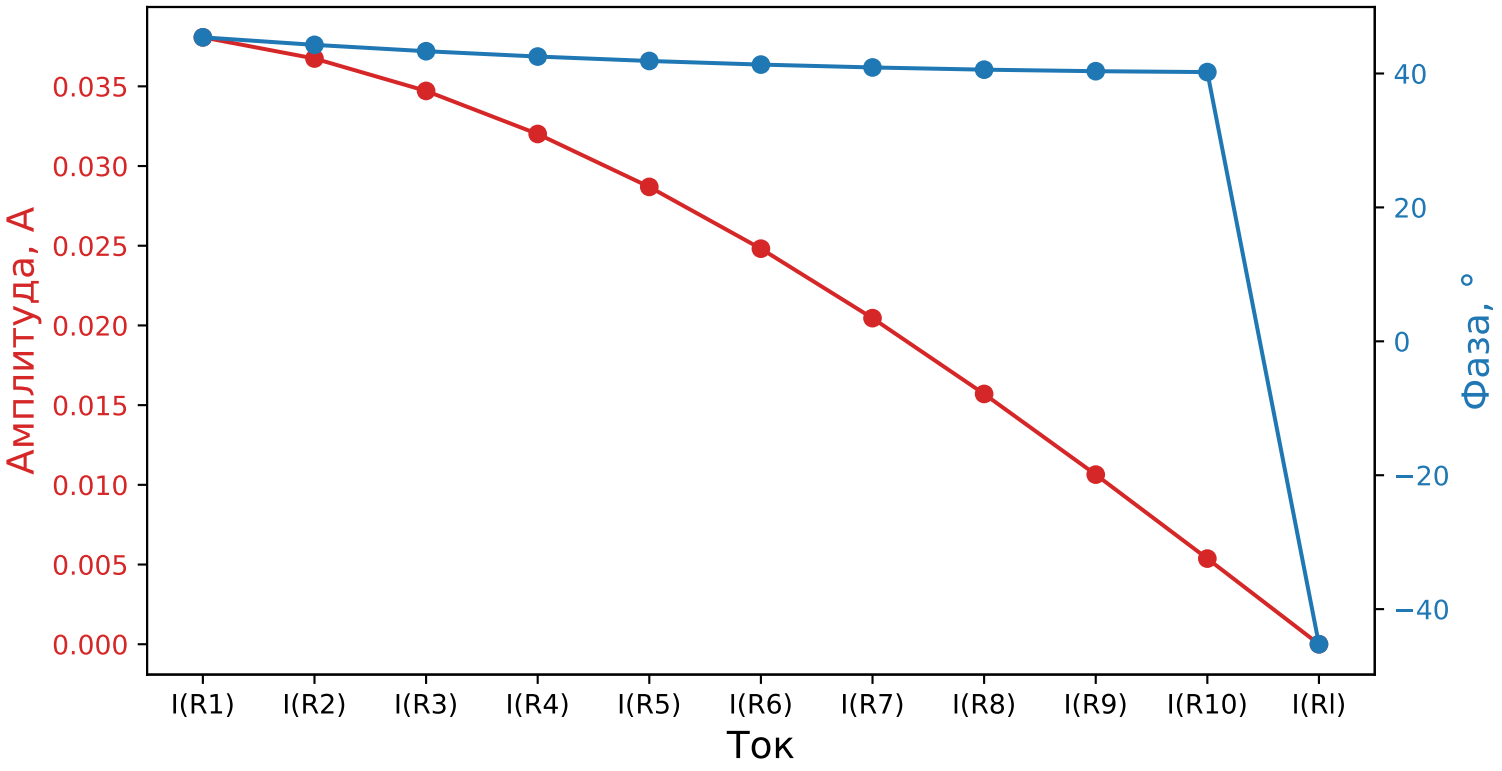


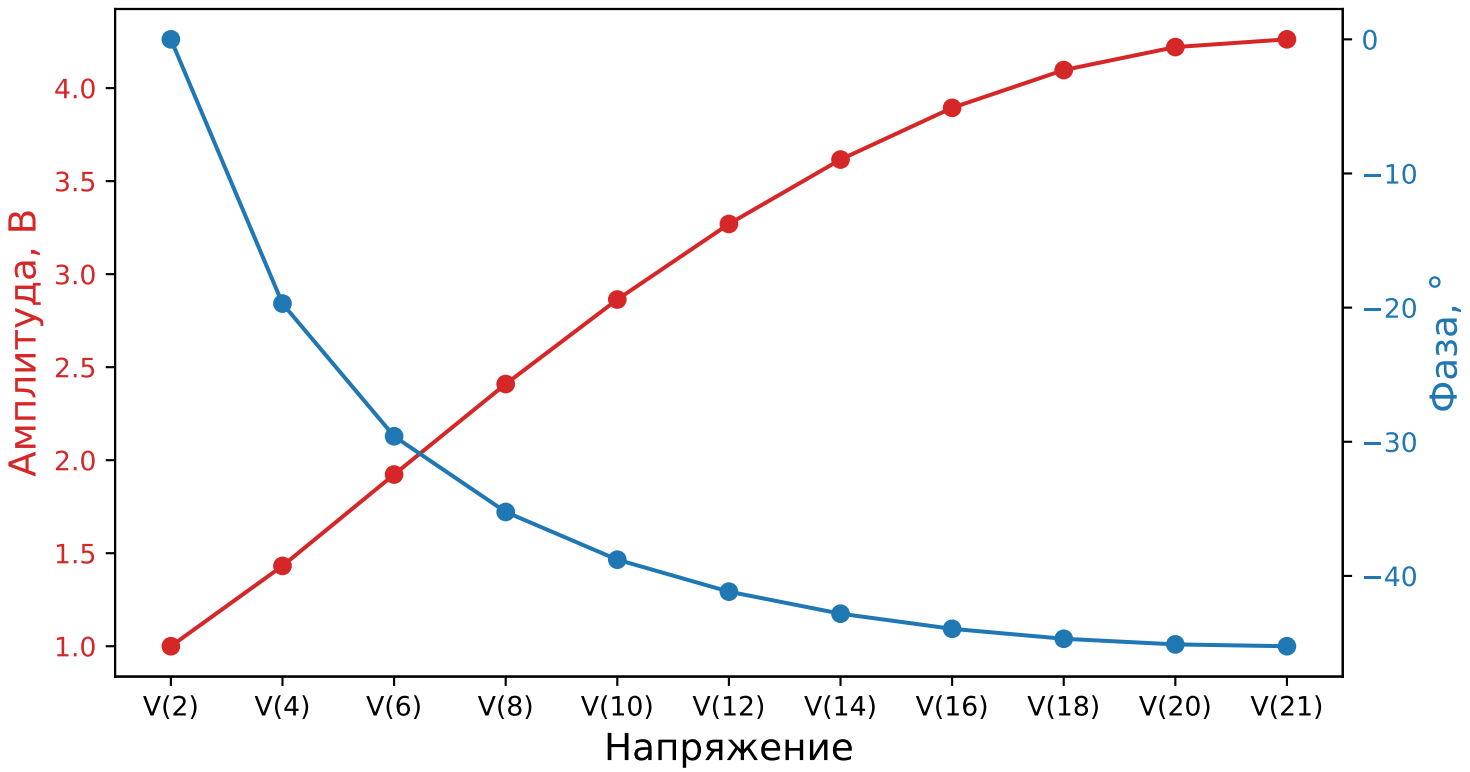
Согласованная нагрузка



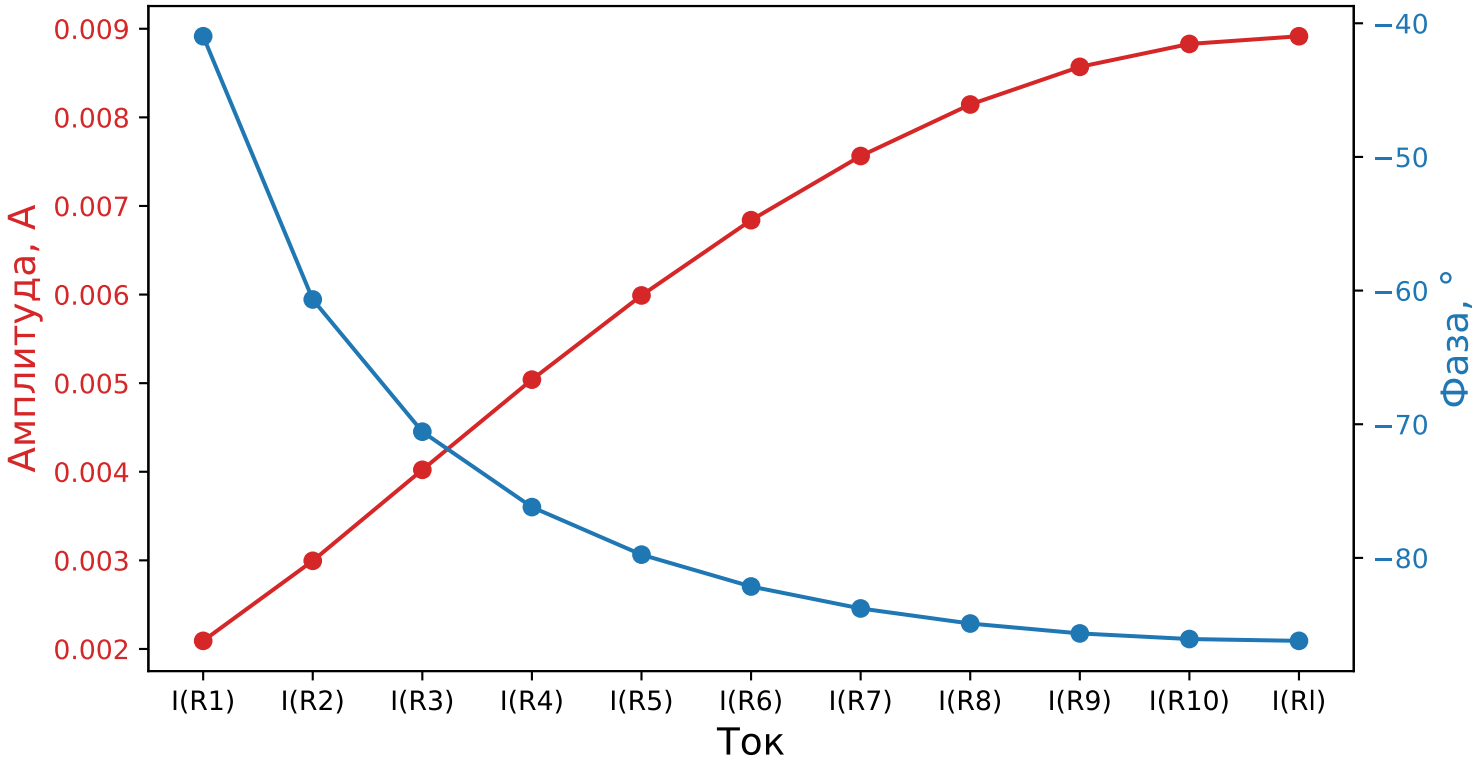


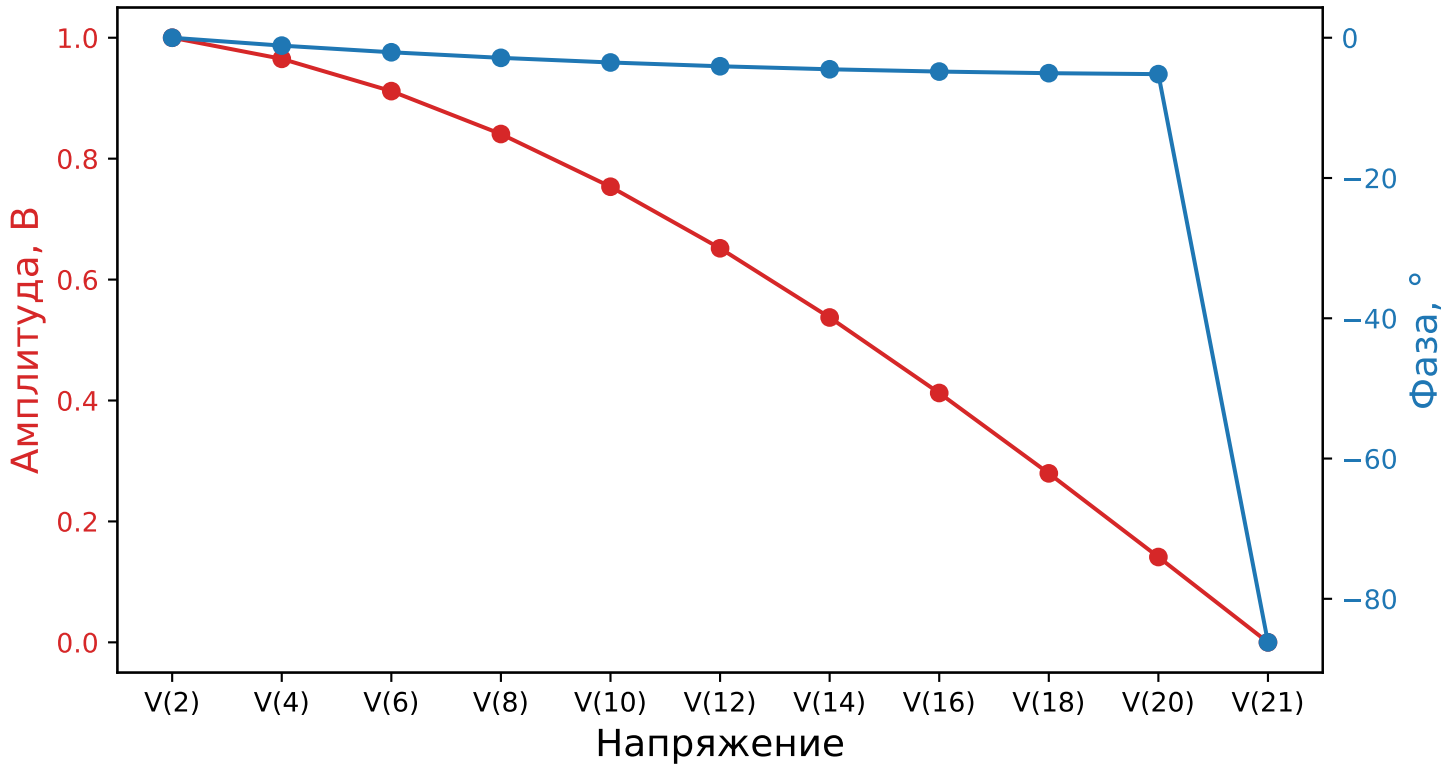
Холостой ход





Короткое замыкание





Активная нагрузка