

APPLICATION OF EXCEL IN THREE - PHASE CIRCUIT ANALYSIS

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SUMMARY

This paper illustrates the application of one component of OFFICE package - Excel - in circuit theory and describes two special programs for the three-phase circuits in harmonic steady state analysis. In the first order it is shown how to access that the basic functions of Excel will work with complex numbers, further all two programs are described and illustrated. First of them is for the connection format of three-phase appliance Y analysis and the second for the appliance of connection format D analysis. Three-phase circuit with the appliance of connection format Y analysis means phase current computing, as well as the real, reactive and complex power transmitted by three-phase load and reactive and complex power on the appliance. Three-phase circuit with the appliance of connection format D analysis means phase and load current computing, the real, reactive and complex power transmitted by three-phase load and real, reactive and complex power on the appliance. Both these programs grant to draw the phasor diagram of voltage and current phasors as graphic representation of the results. The failure states (short connection or disconnection of some phase) analysis is also possible. These programs can be found on the <http://www.tuke.sk/fei-kteem/aei06/y.xls> and <http://www.tuke.sk/fei-kteem/aei06/d.xls>. Presented programs grant to do the full analysis of three-phase circuits. Our goal is to prepare studying materials for the course Theory of electrical engineering with included programs in Excel for graphical illustration of analysis results for the circuits with anharmonic sources, graphic illustration of analysis results for the simple circuits with pulse on the input, full computer processing of long distance line analysis including graphics illustration of results.

Keywords: theory of electrical engineering, three-phase circuit, three-phase load, three-phase appliance

1. INTRODUCTION

The restructuring of our university study brings the changes of contents as well as forms of study and methods of control the study results. This situation results in the requirement to prepare the new study materials. These materials are preparing in the electronic form and will be complete with some computing programs. For the easy availability of these materials we are using usual computer technique and software – operating system Windows and package OFFICE. Some kind of circuits are suitable for developing the general mathematic prescription for which is easy to make a computer program for solving inclusive of its graphic representation. The other kind of circuits is not suitable for such a general mathematic prescription, but graphic illustration of the results are also very useful. Till now developed computer programs for analysis of three-phase circuits with the appliance of connection format Y and connection format D. In this case we used one component of package Office – Excel.

2. THREE-PHASE CIRCUIT ANALYSIS

The three-phase circuit consists of three-phase source, three-phase load and three-phase appliance. The analysis of these circuits in harmonic steady state means in the first order phase and load currents calculation. These calculations were made in the complex area after the substitution the time behavior to phasor.

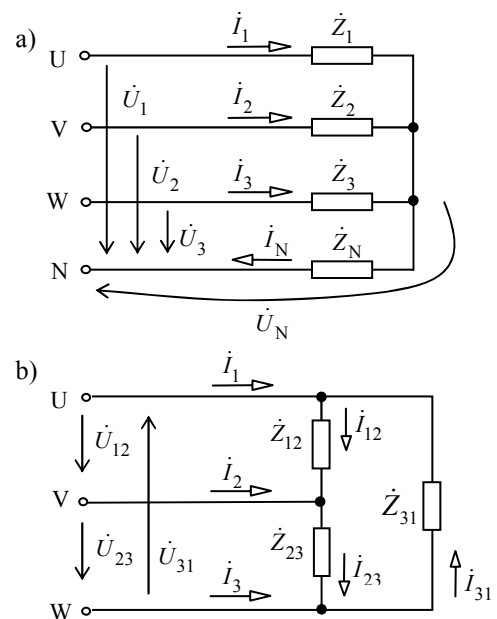


Fig.1 Appliance connection a) Y b) D

The three-phase appliance can be connected in the form of Y or D (Fig.1). This paper deals with both appliance connections.

In connection format Y are phase currents identical with lead currents and for their phasors is

$$\begin{aligned} \dot{I}_1 &= (\dot{U}_1 - \dot{U}_N) \dot{Y}_1, \\ \dot{I}_2 &= (\dot{U}_2 - \dot{U}_N) \dot{Y}_2, \\ \dot{I}_3 &= (\dot{U}_3 - \dot{U}_N) \dot{Y}_3. \end{aligned} \quad (1)$$

where

$$\dot{U}_N = \frac{\dot{U}_1 \dot{Y}_1 + \dot{U}_2 \dot{Y}_2 + \dot{U}_3 \dot{Y}_3}{\dot{Y}_1 + \dot{Y}_2 + \dot{Y}_3 + \dot{Y}_N}; \quad (2)$$

$\dot{U}_1, \dot{U}_2, \dot{U}_3$ is system of phase voltages and for the balanced three-phase source is defined like

$$\begin{aligned} \dot{U}_1 &= U_f e^{j\varphi_0} \text{ V}, \\ \dot{U}_2 &= U_f e^{j(\varphi_0 - 120^\circ)} \text{ V}, \\ \dot{U}_3 &= U_f e^{j(\varphi_0 + 120^\circ)} \text{ V}; \end{aligned} \quad (3)$$

\dot{Y}_1, \dot{Y}_2 and \dot{Y}_3 are admittances of 1., 2. and 3. phase of connection format Y appliance;

\dot{Y}_N is admittance of neutral wire.

In connection format D phase currents are not identical with lead currents and

- phasors of the phase currents are

$$\dot{I}_{12} = \frac{\dot{U}_{12}}{\dot{Z}_{12}}, \quad \dot{I}_{23} = \frac{\dot{U}_{23}}{\dot{Z}_{23}}, \quad \dot{I}_{31} = \frac{\dot{U}_{31}}{\dot{Z}_{31}} \quad (4)$$

where

$\dot{Z}_{12}, \dot{Z}_{23}$ and \dot{Z}_{31} are impedances of 1., 2. and 3. phase of connection format D appliance;

$\dot{U}_{12}, \dot{U}_{23}, \dot{U}_{31}$ is system of load voltages and for the balanced three-phase source is defined like

$$\begin{aligned} \dot{U}_{12} &= U_S e^{j\varphi_0} \text{ V}, \\ \dot{U}_{23} &= U_S e^{j(\varphi_0 - 120^\circ)} \text{ V}, \\ \dot{U}_{31} &= U_S e^{j(\varphi_0 + 120^\circ)} \text{ V}; \end{aligned}$$

- phasors of the load currents are

$$\begin{aligned} \dot{I}_1 &= \dot{I}_{12} - \dot{I}_{31}, \\ \dot{I}_2 &= \dot{I}_{23} - \dot{I}_{12}, \\ \dot{I}_3 &= \dot{I}_{31} - \dot{I}_{23}. \end{aligned} \quad (5)$$

The real, reactive and complex power are calculated as well and

- complex power transmitted by three-phase load is

$$\dot{S} = \dot{U}_1 \dot{I}_1 + \dot{U}_2 \dot{I}_2 + \dot{U}_3 \dot{I}_3 \quad (6)$$

for both appliance connections,

- complex power on the appliance is for connection format Y:

$$\dot{S}' = \dot{S}'_1 + \dot{S}'_2 + \dot{S}'_3 = \quad (7)$$

$$= (\dot{U}_1 - \dot{U}_N) \dot{I}_1 + (\dot{U}_2 - \dot{U}_N) \dot{I}_2 + (\dot{U}_3 - \dot{U}_N) \dot{I}_3,$$

for connection format D:

$$\dot{S}' = \dot{S}'_{12} + \dot{S}'_{23} + \dot{S}'_{31} = \quad (8)$$

$$= \dot{U}_{12} \dot{I}_{12} + \dot{U}_{23} \dot{I}_{23} + \dot{U}_{31} \dot{I}_{31}.$$

3. PROGRAM DESCRIPTION

In the first order it is necessary to access that the functions will work with complex numbers (CN). For the Excel 97 and 2000 it means to activate **Analytic Tools** in the panel **Tools – Accessories**.

This activation enables to use the functions [1]:

COMPLEX - returns CN with taking symbol of imaginary unit,

IMREAL - returns the real part of CN,

IMAGINARY - returns the imaginary part of CN,

IMSUM - returns the sum of two or more CN,

IMSUB - returns the subtraction of two CN,

IMPRODUCT - returns the product of two or more CN,

IMDIV - returns the ratio of two CN,

IMARGUMENT - returns the amplitude of CN,

IMABS - returns the module of CN

Apart from these functions the other ones were used:

DEGREES - returns conversion radians to degrees,

RADIANS - returns conversion degrees to radians,

ROUND - returns number rounded to talking numbers of digits.

Two programs for analysis of three-phase circuits were developed – for three-phase circuit with the appliance of connection format Y (y.xls) and for three-phase circuit with the appliance of connection format D (d.xls). Both programs consists of five basic parts:

- Defined,
- Conversion,
- Relations,
- Solution,
- Phasor diagram.

a) The part **Defined**

In this part parameters of solved circuit are defined. For connection format Y are defined phase voltage phasors $\dot{U}_1, \dot{U}_2, \dot{U}_3$, impedances of all three phases

Y format appliance $\dot{Z}_1, \dot{Z}_2, \dot{Z}_3$ and neutral wire impedance \dot{Z}_N (Fig.2a). For connection format D

load voltage phasors $\dot{U}_{12}, \dot{U}_{23}, \dot{U}_{31}$ and impedances of all three phases D format appliance $\dot{Z}_{12}, \dot{Z}_{23}, \dot{Z}_{31}$ are defined (Fig.2b).

a)

	A	B	C
1	Phase voltage phasor	Modul	Argument
2	U1 [V]	230	0
3	U2 [V]	230	-120
4	U3 [V]	230	120
5	Impedance phases appliance		
6	Z1 [Ω]	100	45
7	Z2 [Ω]	10	-45
8	Z3 [Ω]	100	90
9	ZN [Ω]	5	15

Fig. 2. a) Defined parameters and their conversion on the CN for format Y

b)

C6 = 45			
	A	B	C
1	Load voltages	Modul	Argument
2	U12 [V]	400	30
3	U23 [V]	400	-90
4	U31 [V]	400	150
5	Impedance phases appliance		
6	Z12 [Ω]	100	45
7	Z23 [Ω]	150	80
8	Z31 [Ω]	100	90

Fig. 2. b) Defined parameters and their conversion on the CN for format D.

b) The part **Conversion**
 Excel does not work with CN in exponential form, so it is necessary to convert all complex circuits parameters from the exponential to algebraic form. The function COMPLEX is used on this purpose and is presented in the top of Fig.3. We would like that you pay attention all functions used as illustrations of program operation are shown in the top of corresponding figure.

E2 = =COMPLEX(H2;I2;"j")

	E	H	I
1	Komplex	Re[U]	Im[U]
2	346,410161513776+200j	346,41	200

Fig.3 Conversion of input parameters to CN

c) The part **Relations**
 The first step of analysis is the calculation of \dot{U}_N by the term (2) for three-phase circuit with the appliance of connection format Y. The numerator and denominator of the term (2) as well as resultant relationship for \dot{U}_N are illustrated in the top of Fig.4a and Fig.4b.

a)

H11 = =IMSUM(IMDIV(E2;E6);IMDIV(E3;E7);IMDIV(E4;E8))

	G	H
10		
11	Numerator	9,57104206279124-22,6926396013777j
12	Denominator	0,270966911188334+1,87580128628513E-003j

H12 = =IMSUM(IMDIV(1;E6);IMDIV(1;E7);IMDIV(1;E8);IMDIV(1;E9))

	G	H
10		
11	Numerator	9,57104206279124-22,6926396013777j
12	Denominator	0,270966911188334+1,87580128628513E-003j

E11 = =IMDIV(H11;H12)

	D	E
11	UN=	34,7403982028891-83,9873975210023j

Fig. 4. a) \dot{U}_N evaluation

b)

B11 = =ROUND(IMABS(E11);2)

	A	B	C	D	E
11	UN [V]	90,89	-67,53	UN=	34,7403982028891-83,9873975210023j

C11 = =ROUND(DEGREES(IMPARGUMENT(E11);2)

	A	B	C	D	E
11	UN [V]	90,89	-67,53	UN=	34,7403982028891-83,9873975210023j

Fig. 4. b) \dot{U}_N evaluation

The next step of analysis is determination of the voltages on the all appliance phases as subtractions $\dot{U}_1 - \dot{U}_N$, $\dot{U}_2 - \dot{U}_N$, $\dot{U}_3 - \dot{U}_N$ in the term (1) and it is shown in the Fig.5.

E15 = =IMSUB(E2;E11)

	A	B	C	E
13	Voltages			
14	on the appliance			
15	U1' [V]	212,56	23,27	195,259601797111+83,9873975210023j
16	U2' [V]	188,93	-142,4282	-149,7403982028891-115,198445349419j

Fig. 5 Voltages of appliance phases computing

The basic step of analysis is determination of phase and load current phasors for three-phase circuit with the appliance of connection format D. This step is illustrated in the Fig. 6a and 6b.

a)

E10 = =IMDIV(E2;E6)

	A	B	C	D	E
9	Phase currents				
10	I12 [A]	4	-15		3,86370330515628-1,03527618041008j

E10 = =IMDIV(E2;E6)

	E
10	3,86370330515628-1,03527618041008j

b)

E14 = =IMSUB(E10;E12)

	A	B	C	D	E
13	Load currents				
14	I1 [A]	4,87	-68		1,86370330515628-4,49937779554783j

E14 = =IMSUB(E10;E12)

	E
14	1,86370330515628-4,49937779554783j

Fig. 6 a) Phase current computing for format D b) Load current computing for format D

The power calculations are made according to terms (6) - (8). Complex power on the appliance of format D calculation is illustrated in the Fig. 7, corresponding real and reactive power calculation is illustrated in the Fig. 8a and 8b. The functions on the top of Fig. 7 and 8 are used for calculating complex, real and reactive power on the appliance of format Y such as for format D.

B22		= ROUND(IMREAL(E18);2)	
	A	B	C
22	P1 [W]	1131,37	
23	P2 [W]	185,22	

B26		= ROUND(IMAGINARY(E18);2)	
	A	B	C
26	Q1 [VAr]	1131,37	
27	Q2 [VAr]	1050,46	

Fig. 8 Calculation of the a) real power b) reactive power for appliance of format D.

d) The part **Results:**

The complete analysis results for the appliance of format D is in the Fig. 9a and for the appliance of format Y is in the Fig. 9b.

a)				b)			
	A	B	C		A	B	C
18	Phase currents			9	Phase currents		
19	I1 [A]	2,13	-21,73	10	I12 [A]	4	-15
20	I2 [A]	18,89	-97,43	11	I23 [A]	2,67	-170
21	I3 [A]	3,2	27,87	12	I31 [A]	4	60
22	Neutral wire currents			13	Load currents		
23	IN [A]	18,18	-82,53	14	I1 [A]	4,87	-68
24	Appliance consumption powers			15	I2 [A]	6,52	175
25	S1 [VA]	451,8	45	16	I3 [A]	6,07	40,3
26	S2 [VA]	3569,29	-45	17	Appliance consumption powers		
27	S3 [VA]	1026,09	90	18	S12 [VA]	1600	45
28	SN [VA]	1652,16	15	19	S23 [VA]	1066,67	80
29	S [VA]	4502,22	-9,6	20	S31 [VA]	1600	90
30	P1 [W]	319,47		21	S [VA]	4004,46	70,8
31	P2 [W]	2523,87		22	P1 [W]	1131,37	
32	P3 [W]	0		23	P2 [W]	185,22	
33	PN [W]	1595,86		24	P3 [W]	0	
34	P [W]	4439,2		25	P [W]	1316,6	
35	Q1 [VAr]	319,47		26	Q1 [VAr]	1131,37	
36	Q2 [VAr]	-2523,87		27	Q2 [VAr]	1050,46	
37	Q3 [VAr]	1026,09		28	Q3 [VAr]	1600	
38	QN [VAr]	427,61		29	Q [VAr]	3781,83	
39	Q [VAr]	-1178,3		30	Line transmission powers		
40	Line transmission powers			31	S12' [VA]	1124,7	67,5
41	S1' [VA]	488,88	21,73	32	S23' [VA]	1504,58	65
42	S2' [VA]	4345,29	-22,57	33	S31' [VA]	1401,41	79,7
43	S3' [VA]	4345,29	92,13	34	S' [VA]	4004,46	79,7
44	S' [VA]	4502,22	-9,6	35	P1' [W]	430,4	
45	P1' [W]	454,15		36	P2' [W]	634,94	
46	P2' [W]	4012,43		37	P3' [W]	251,25	
47	P3' [W]	-27,39		38	P' [W]	1316,6	
48	P' [W]	4439,2		39	Q1' [VAr]	1039,09	
49	Q1' [VAr]	180,97		40	Q2' [VAr]	1364,05	
50	Q2' [VAr]	-1667,9		41	Q3' [VAr]	1378,7	
51	Q3' [VAr]	736,24		42	Q' [VAr]	3781,83	
52	Q' [VAr]	-750,69					

Fig.9 Analysis results for appliance format a) Y b) D

e) The part **Phasor diagram**

The phasor diagram of voltage and current phasors is in the Fig.10a) for the appliance of format Y and

in the Fig.10b) for the appliance of format D. Because of very different voltage and current amplitudes was the current amplitude proportional adapted (Fig.11).

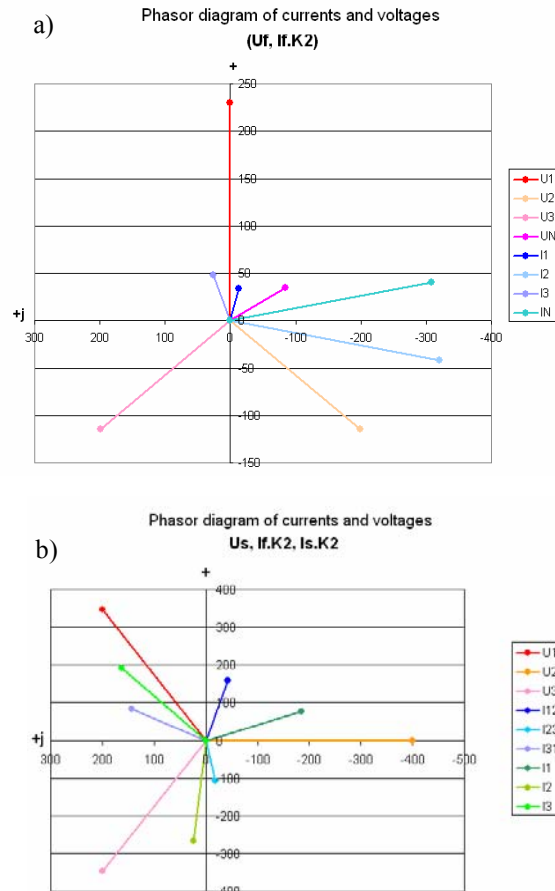


Fig. 10 The phasor diagram of voltage and current phasors a) for the appliance of format Y b) for the appliance of format D

G22		= 0,6*(SUMA(B2:B4)/3)/(SUMA(B14:B16)/3)	
	F	G	H
22	K2=	41,23711	

Fig. 11 The example proportional adapted currents for phasor diagram

CONCLUSION

Presented programs grant to do the full analysis of three-phase circuits with appliance connected in the form Y and in the form D. The failure states (short connection or disconnection of some phase) analysis is also possible, but impedance of short connection phase is suggested to be simulated by number 10^{-20} (not by 0) and impedance of disconnection phase is suggested to be simulated with number 10^{20} .

These programs can be found on the <http://www.tuke.sk/fei-kteem/aei06/y.xls> and <http://www.tuke.sk/fei-kteem/aei06/d.xls>. They can be used in Open Office, which is unlike Excel free.

Our goal is to prepare studying materials for the course Theory of electrical engineering with included programs in Excel for

- graphical illustration of analysis results for the circuits with anharmonic sources,
- full computer processing three-phase circuits analysis with graphic illustration of results in the form of phasor diagrams,
- graphic illustration of analysis results for the simple circuits with pulse on the input,
- full computer processing of long distance line analysis including graphics illustration of results.

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BIOGRAPHIES

Darina Špaldonová (doc, RNDr, CSc) was born in Košice in 1954. In 1976 she graduated at P. J. Šararik University in Košice, in 1983 received the RNDr (MSc) degree at this university and in 1994 CSc (PhD) degree in theory of electrical engineering at Slovak University of Technology, Bratislava. In 1998 she was appointed Associate Professor of theory of electrical engineering at the Department of Electrical engineering and Electrical Measurement of the Technical university of Košice. Her current interests include circuit theory and theory of electromagnetic field.

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