Rectifiers

1. Objectives

The purpose of this exercise is to familiarize students with the structure and properties of basic rectifier systems: half-wave rectifier, full-wave rectifier with center-tap transformer and bridge (Graetz) rectifier.

2. Components and instrumentation.

The schematics of rectifiers are shown in Fig.1. Each type of rectifier (half-wave, full-wave with center-tap transformer, bridged) can be assembled on the PCB shown in Fig.2. Connection of the transformer and the rectifier input are shown in Fig. 1. The load is in the form of a high power resistor.

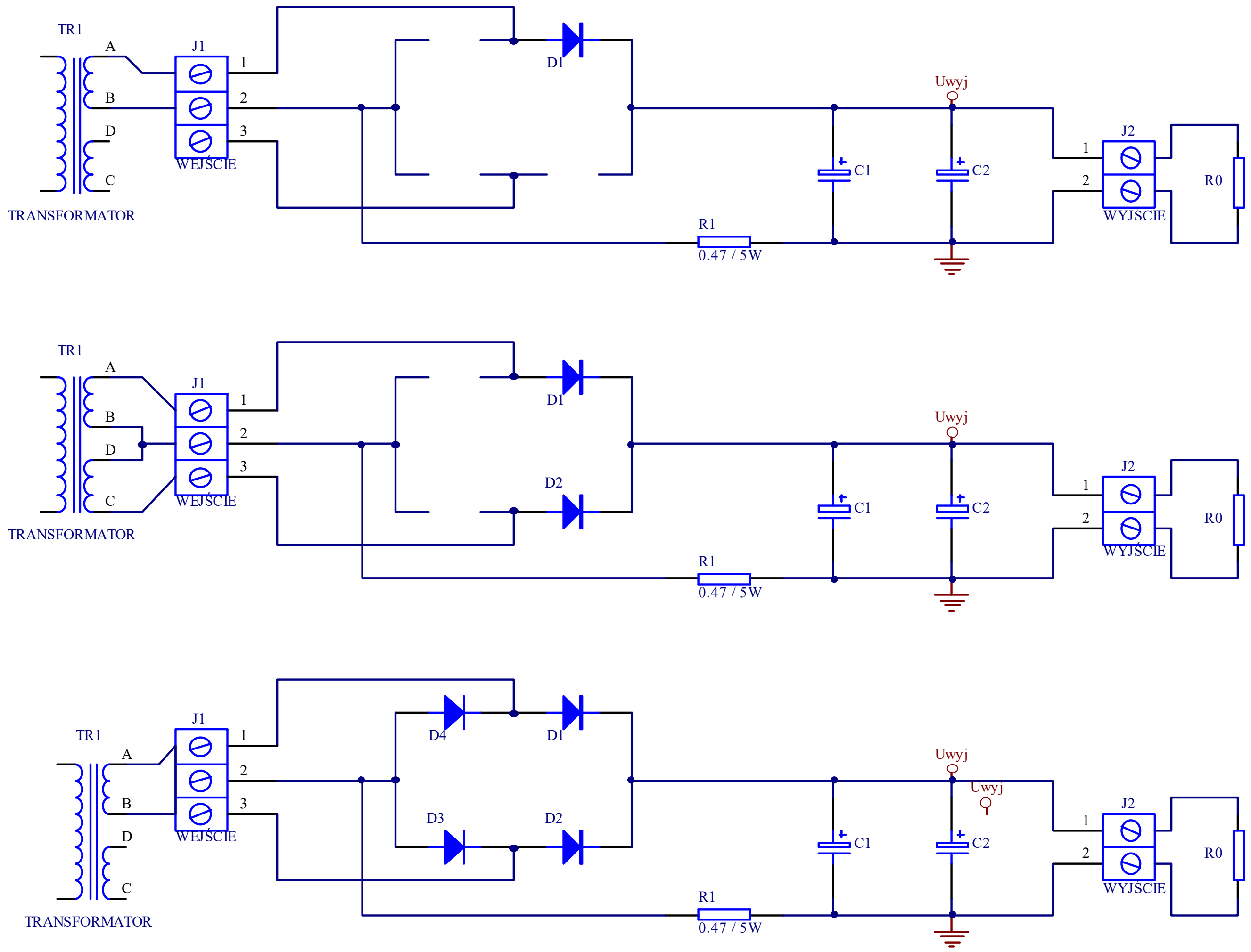

Fig.1. Schematic of rectifiers under consideration:
(a) – half-wave, (b) – full-wave with center-tap transformer, (c) -bridge.

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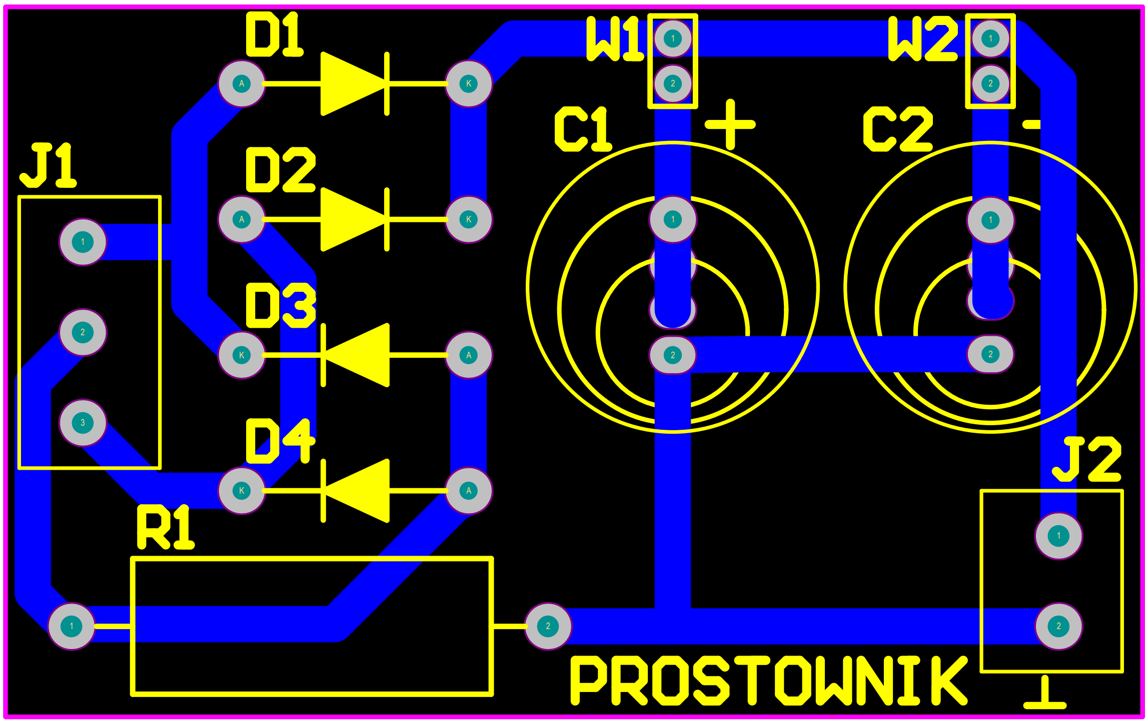

Fig.2. PCB of rectifiers. All of rectifiers described can be assembled on the PCB. Elemets view.

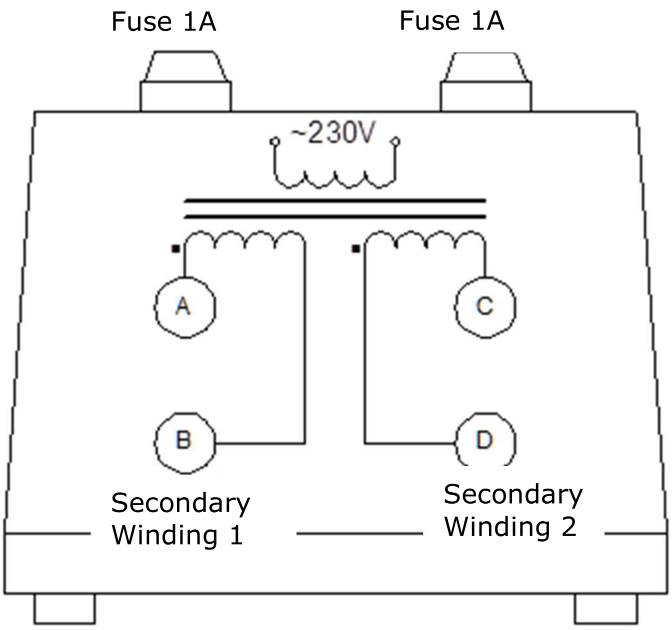

Fig.3. Transformer.

3. Preparation.

NOTE: Estimated time for preparation is 3 to 6 hours.

3.1. References

[1] Lab materials and lectures of the course.

[2] U. Tietze, Ch. Schenk, Electronic circuits. Handbook for Designe and Applications, Springer, 2008, p. 885-892.

[3] P. Horowitz, W. Hill, The Art of Electronics, Cambridge Univ. Press, London, 2015,

3.2. Test questions

1. What is the RMS voltage and current ? Calculate the RMS values of:
    a. Sine-wave of an amplitude of 100V,
    b. Sum of sine-wave from (a) and DC voltage of 20V,
    c. Rectangular wave of an amplitude of 10V and duty factor of ¼,
2. What is the average value of voltage and current ? Calculate the average values of voltages from question 1.
3. What are the real, passive and apparent power ?
4. What is the crest factor of current or voltage ?
5. What is the form factor of currents or voltage ?
6. What is the power factor ?
7. Draw and explain the operation principle of: half-wave rectifier, full-wave center tapped rectifier and bridge rectifier.
8. Draw waveforms of voltages and currents of the rectifiers with resistive and capacitor-resistive load.
9. What is the maximum reverse voltage across diodes in rectifiers under consideration ?
10. What is the idel voltage in rectifiers under consideration ?
11. How ripple voltage depends from capacitor of the rectifier ?

3.3. Project task

For chosen type of rectifier (half-wave, full-wave with center-tapped transformer, bridge) calculate all parameters using analytic method [2] and graphical [1] (instead of analytic method one can apply computer simulation). Results put in proper Tables 2-x, (6 tables) and Table.3 Parameters to calculate are:

- U_{00AV} – average idle voltage (rectifier with no load),
- U_{0AV} – average output voltage (with load),
- U_{0MIN} – minimum output voltage (with load),,
- U_{0RMS} – RMS output voltage (with load),
- U_{0MAX} – maximum output voltage (with load),
- $U_{0RIP(PP)}$ – ripple output voltage (with load),,
- I_{0AV} – average load current equal to average diode current (with load),
  In full-wave rectifiers each diode have the current twice smaller;
- I_{DMAX} – repetitive maximum diode current,

- I_{DRMS} – RMS diode current,
  In full-wve rectifiers each diode have √2 times smaller current than RMS current of the transformer.
- PRs – real power dissipated in transformer,
- CF –crest factor of diode current = IDMAX/IDRMS;
- FF – form factor of diode current = $I_{DRMS}/|I_D|_{AV}$;
- Δt – conductive time of diode,
- PF –power factor (PC) referred to rectifier input.
- I_{DSURGE} – inrush current or input surge current (when switching on the circuit),

Calculations should be done for:

- Chosen rectifier with resistive load (no capacitor) $R_0 = R_{01}$ i $R_0 = R_{02}$,

And for 4 combination of capacitors and resistor loads:

- capacitor $C = C_1$ (smaller value of C_1 and C_2) and load $R_0 = R_{01}$,
- capacitor $C = C_1$, and load $R_0 = R_{02}$,
- capacitor $C = C_1 + C_2$, load $R_0 = R_{01}$,
- capacitor $C = C_1 + C_2$, load $R_0 = R_{02}$.

For calculations chose date as follows:

- secondary RMS voltage $E_{RMS} = 12.5V$,
- turn ratio n = 18.4,
- resistivity of primary winding $R_{primary} = 300\ \Omega$
- resistivity of secondary winding $R_{secondary} = 3{,}8\ \Omega$.
  ***Note**: in calculations, to internal transformer resistivity one should add current shunt resistor (R1 = 0.47 Ω, see Fig.1)*

$$R_S = R'_S + 0{,}47\ \Omega.$$

3.4. The course of the exercise:

3.5. Transformer internal resistivity (R_S)

Transformer with reference to output is a two pole circuit (Thevenin theorem) as in Fig.4.

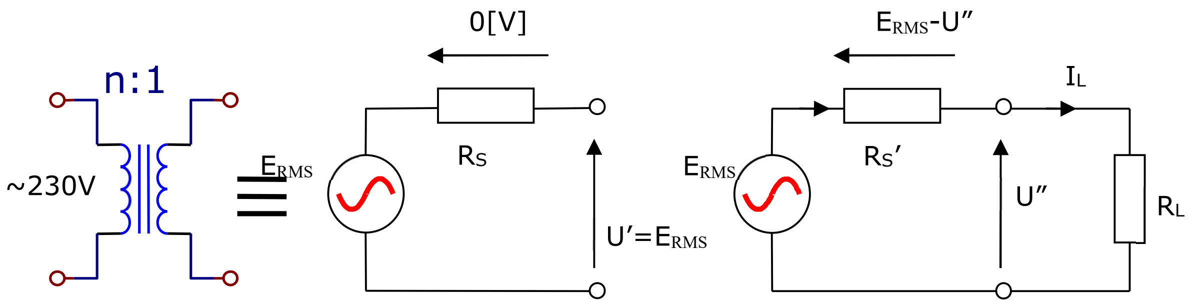

Fig. 4. Transformer equivalent circuit referred to secondary winding.

Measurement of R_S' resistance consists in measuring the electromotive force E with a very high internal resistance voltmeter (the universal digital meter has resistances of the order of 10MΩ). At the terminals of the transformer unloaded, we obtain the result U'= E (transformer terminals A and B or pair C and D - Fig.3). After the transformer load, known as R_L resistance, of the order of 50 to 100Ω, one measure the voltage U". In this measurement one get a result less the voltage drop on the R_S resistor. This voltage drop is:

$$E - U" = R_S^{'} \cdot I_L$$

where:

$$R_S^{'} = \frac{E - U"}{I_L} = \frac{U' - U"}{I_L} = \frac{U' - U"}{U"/R_L} = R_L \frac{U' - U"}{U"}$$

Exact value of R_L one can measure with universal ohm meter.
Results one should put to Table 1.

Note: *real value of equivalent serial resistivity of a transformer must be enlarge of shunt resistor R1=0,47Ω used for current measurements.*

$$R_S = R^{'}_S + 0.47\ \Omega.$$

3.6. Circuit assembling and measurements

1. Assemble the chosen rectifier circuit for which calculations have been performer.
2. To the input of rectifier connect the transformer and to output the load resistor R_{01}; turn on the power.
3. By means of scope observe output voltage and current. (one can assume that $I_{out}=U_{out}/R_{01}$).
4. Using „**measurement**" function of the scope measure all the parameters in Table.2-(1 or 2).
5. Print wave forms of output current and voltage for Tables 2-(1 or 2).
6. Measurement of surge current I_{DSURGE} can be done using **„single"** function of scope and turning od the power to the circuit; print one of the shots.
7. Conductive time of the diode can be measured using „cursor" function of the scope.
8. Repeat measurements 2-5 for load R_{02}.
9. Apply (or turn on) capacitor C_1 (small value) and observe the output voltage and current (current is measured by means of voltage drop on shunt resistor R_1=0,47 Ω).
10. Using a function **„measurements"** of the scope, fill the Tables 2-(3-4) for C_1-R_{01}, C_1-R_{02},
11. Apply (or turn on) capacitor C_2 and repeat measurements for (C_1+C_2)-R_{01}, (C_1+C_2)-R_{02}, fill the Tables 2-(5-6)
12. Fill the Table 6 using previously filled Tables 3.

4. Contest of the report

1. For the rectifier with capacitor filter:
   a. Name parameters that change according to theoretical predictions, with increase of the filter capacity and increase in load (decrease in load resistance).

b. List the parameters that have changed or have not changed and this was not consistent with theoretical predictions.

2. Compare parameters of the rectifier with and without capacitor.
3. How changes the power factor of the circuit, and crest factor and form factor of diode current, for circuits with and without capacitor?

Tabela 1. Equivalent internal resistivity of the transformer.

U' = E [V]	U" [V]	E – U'' [V]	R_L [Ω]	I_L [A]	R_S' [Ω]	R_S' [Ω] obliczone

Table 2-1(Half-wave). Results of measurements. Electromotive force E_{RMS}=………..[V], transformer internal resistivity R_S=……..[Ω]

	Half-wave rectifier without capacitor $R_0 = R_{01}$ = ...[Ω]	
Parameter	Calculations	Measurements
U_{00AV} [V]		
U_{0MAX} [V]		
U_{0MIN} [V]		
$U_{0RIP(PP)}$ [V]		
U_{0AV} [V]		
U_{0RMS} [V]		
I_{0AV} [A]		
I_{DRMS} [A]		
I_{DMAX} [A]		
$CF(I_D)$ MAX/RMS		
$FF(I_D)$ RMS/|AV|		
Δt (czas przewodzenia diody) [ms]		
PF (wsp. mocy)		
P_{Rs} [W]		
I_{DSURGE} [A]		

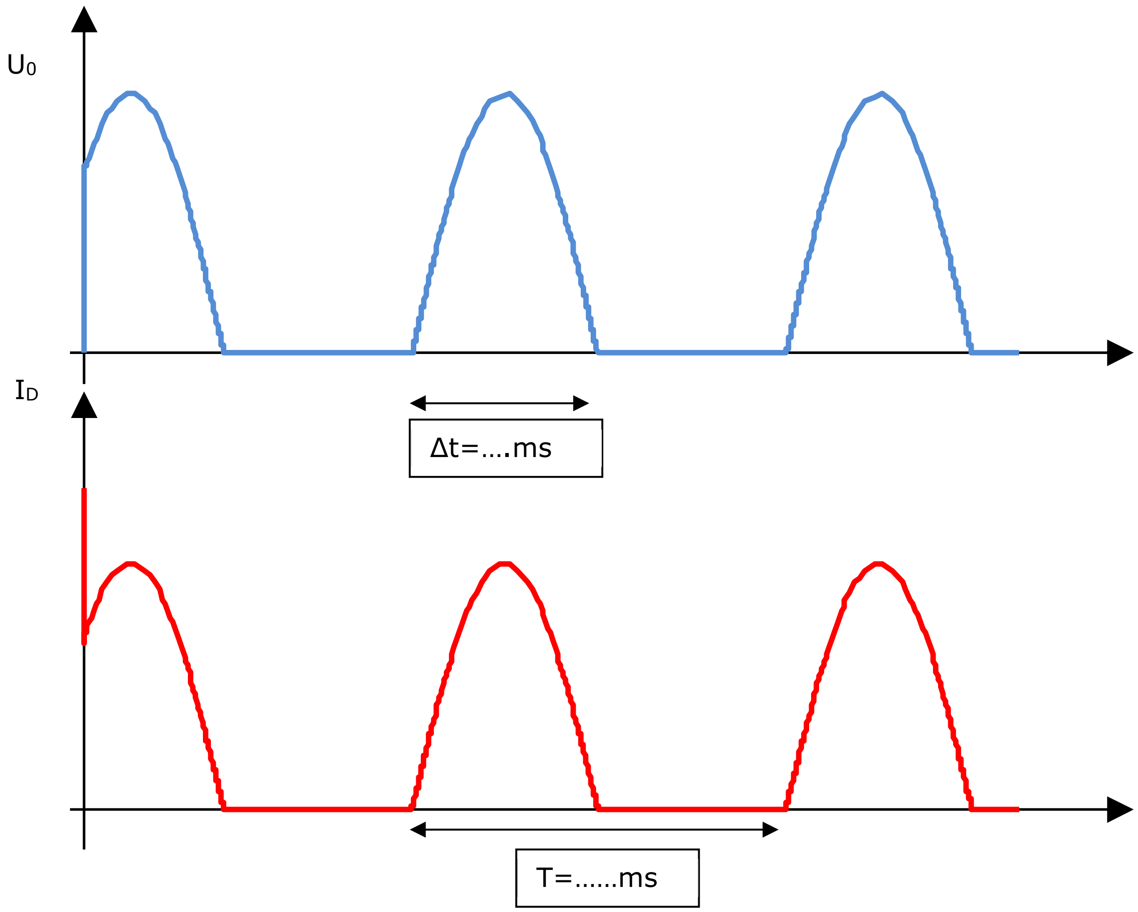

Tabela 2-2(Half_wave). Results of measurements. Electromotive force E_{RMS}=……….[V], transformer internal resistivity R_S=……..[Ω]

	Half-wave rectifier without capacitor $R_0 = R_{02}$ = ...[Ω]	
Parameter	Calculations	Measurements
U_{00AV} [V]		
U_{0MAX} [V]		
U_{0MIN} [V]		
$U_{0RIP(PP)}$ [V]		
U_{0AV} [V]		
U_{0RMS} [V]		
I_{0AV} [A]		
I_{DRMS} [A]		
I_{DMAX} [A]		
$CF(I_D)$ MAX/RMS		
$FF(I_D)$ RMS/|AV|		
Δt (czas przewodzenia diody) [ms]		
PF (wsp. mocy)		
P_{Rs} [W]		
I_{DSURGE} [A]		

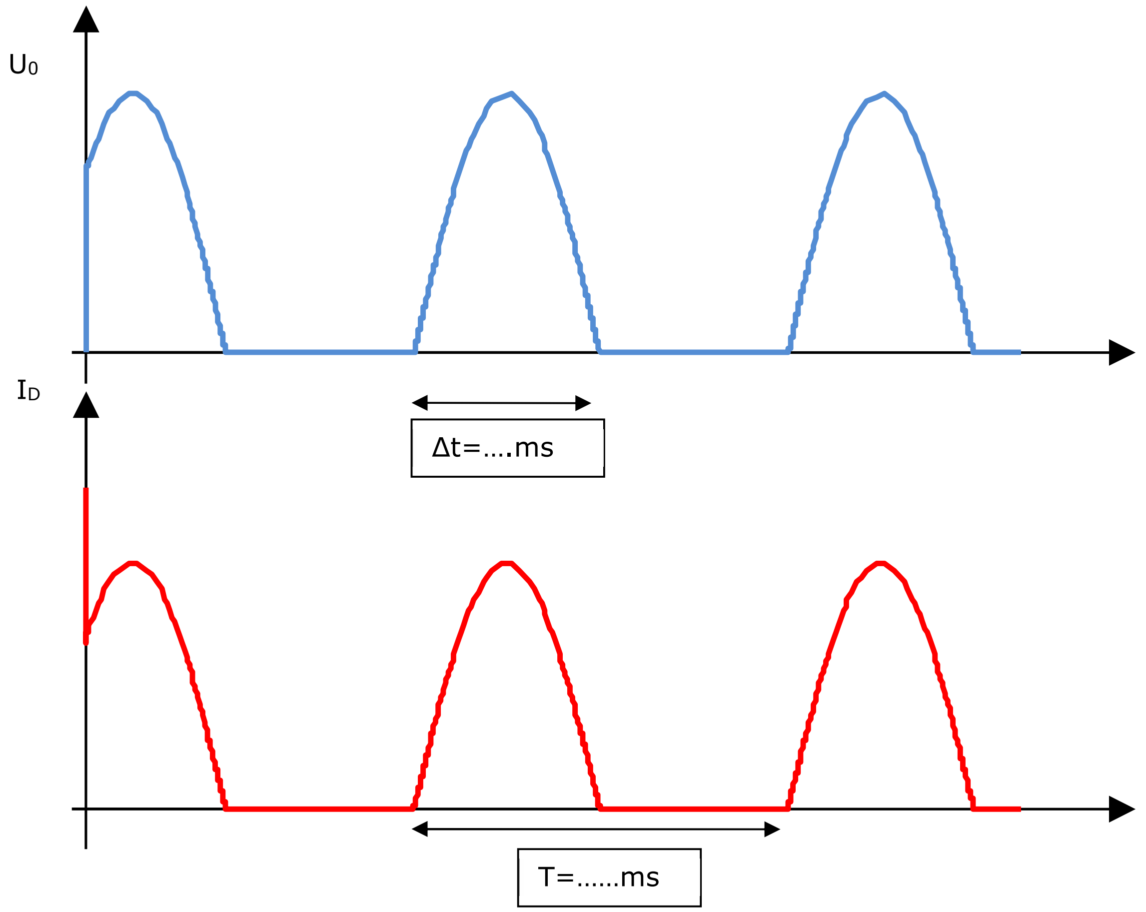

Tabela 2-1(Full-wave). Results of measurements. Electromotive force E_{RMS}=………..[V], transformer internal resistivity R_S=……..[Ω]

	Full-wave rectifier without capacitor $R_0 = R_{01}$ = ...[Ω]	
Parameter	Calculations	Measurements
U_{00AV} [V]		
U_{0MAX} [V]		
U_{0MIN} [V]		
$U_{0RIP(PP)}$ [V]		
U_{0AV} [V]		
U_{0RMS} [V]		
I_{0AV} [A]		
I_{DRMS} [A]		
I_{DMAX} [A]		
$CF(I_D)$ MAX/RMS		
$FF(I_D)$ RMS/|AV|		
Δt (czas przewodzenia diody) [ms]		
PF (wsp. mocy)		
P_{Rs} [W]		
I_{DSURGE} [A]		

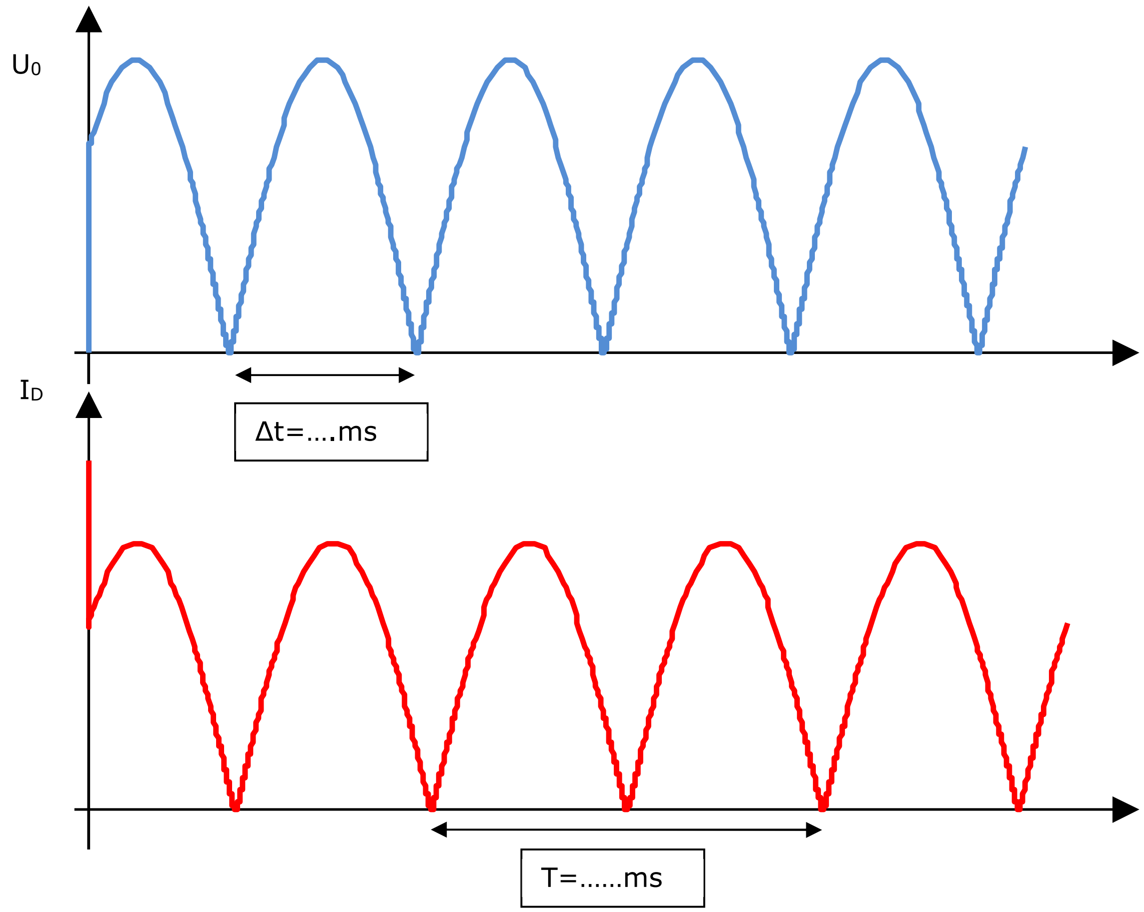

Tabela 2-2(Full-wave). Results of measurements. Electromotive force E_{RMS}=………..[V], transformer internal resistivity R_S=……..[Ω]

	Full-wave rectifier without capacitor $R_0 = R_{02}$ = ...[Ω]	
Parameter	Calculations	Measurements
U_{00AV} [V]		
U_{0MAX} [V]		
U_{0MIN} [V]		
$U_{0RIP(PP)}$ [V]		
U_{0AV} [V]		
U_{0RMS} [V]		
I_{0AV} [A]		
I_{DRMS} [A]		
I_{DMAX} [A]		
$CF(I_D)$ MAX/RMS		
$FF(I_D)$ RMS/|AV|		
Δt (czas przewodzenia diody) [ms]		
PF (wsp. mocy)		
P_{Rs} [W]		
I_{DSURGE} [A]		

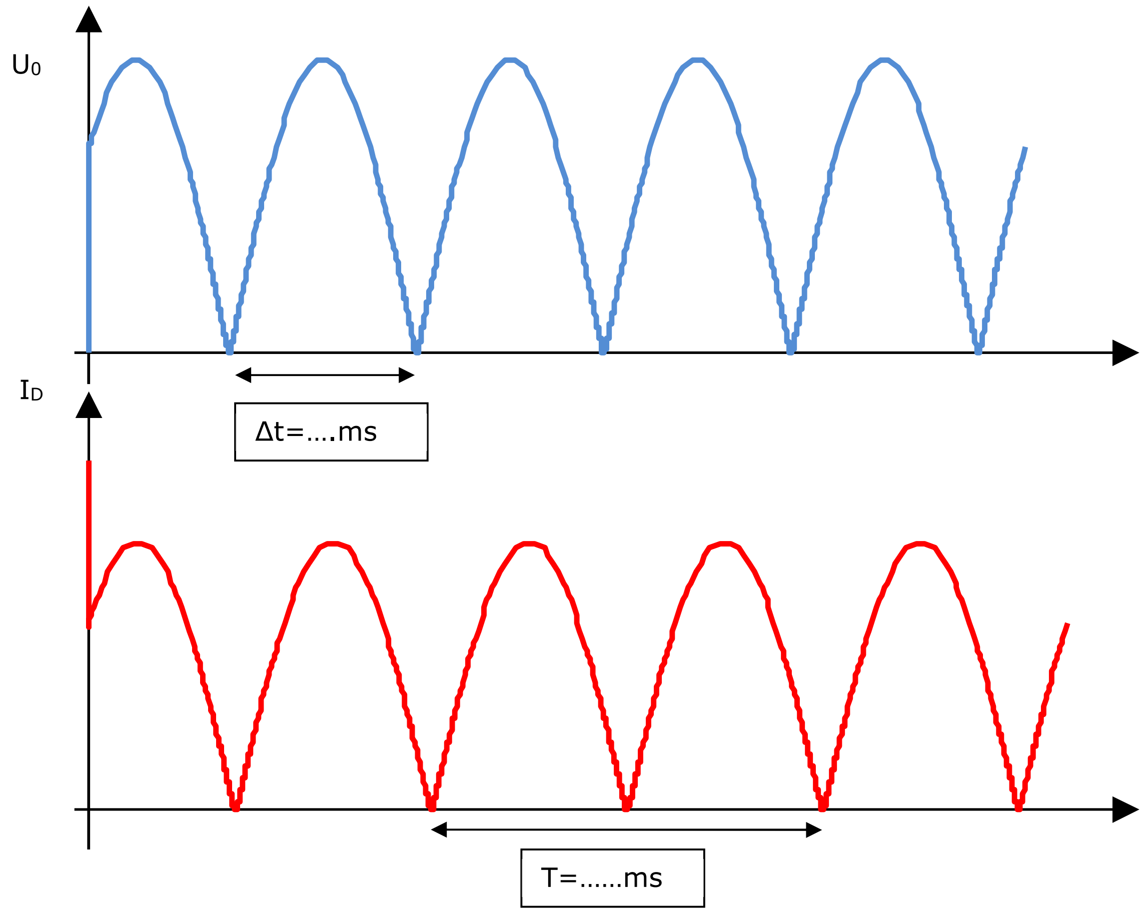

Tabela 2-3. Results of measurements. Electromotive force E_{RMS}=……….[V], transformer internal resistivity R_S=……..[Ω]

	$R_0 = R_{01}$= ....[Ω] C = C_1 =.........[μF] (small value		
Parameter	Calculations	Grapical/simulations	Measurements
U_{00AV} [V]			
U_{0MAX} [V]			
U_{0MIN} [V]			
$U_{0RIP(PP)}$ [V]			
U_{0AV} [V]			
U_{0RMS} [V]			
I_{0AV} [A]			
I_{DRMS} [A]			
I_{DMAX} [A]			
$CF(I_D)$ MAX/RMS			
$FF(I_D)$ RMS/|AV|			
Δt (czas przewodzenia diody) [ms]			
PF (wsp. mocy)			
P_{Rs} [W]			
I_{DSURGE} [A]			

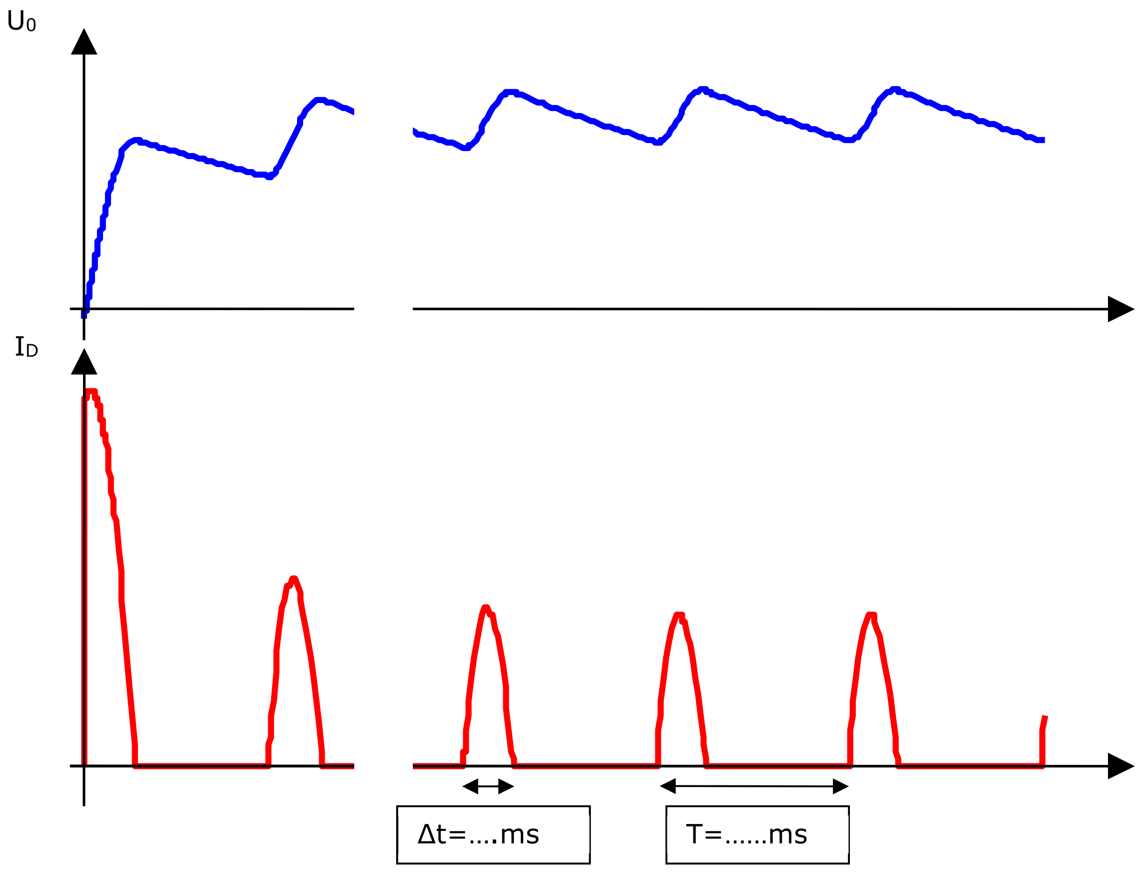

Tabela 2-4. Results of measurements. Electromotive force E_{RMS}=……….[V], transformer internal resistivity R_S=……...[Ω]

	$R_0 = R_{01}$= ....[Ω] $C = C_1+C_2$ =.........[µF] (small value			
Parameter	Calculations	Grapical/simulations	Measurements	
U_{00AV} [V]				
U_{0MAX} [V]				
U_{0MIN} [V]				
$U_{0RIP(PP)}$ [V]				
U_{0AV} [V]				
U_{0RMS} [V]				
I_{0AV} [A]				
I_{DRMS} [A]				
I_{DMAX} [A]				
$CF(I_D)$ MAX/RMS				
$FF(I_D)$ RMS/|AV|				
Δt (czas przewodzenia diody) [ms]				
PF (wsp. mocy)				
P_{Rs} [W]				
I_{DSURGE} [A]				

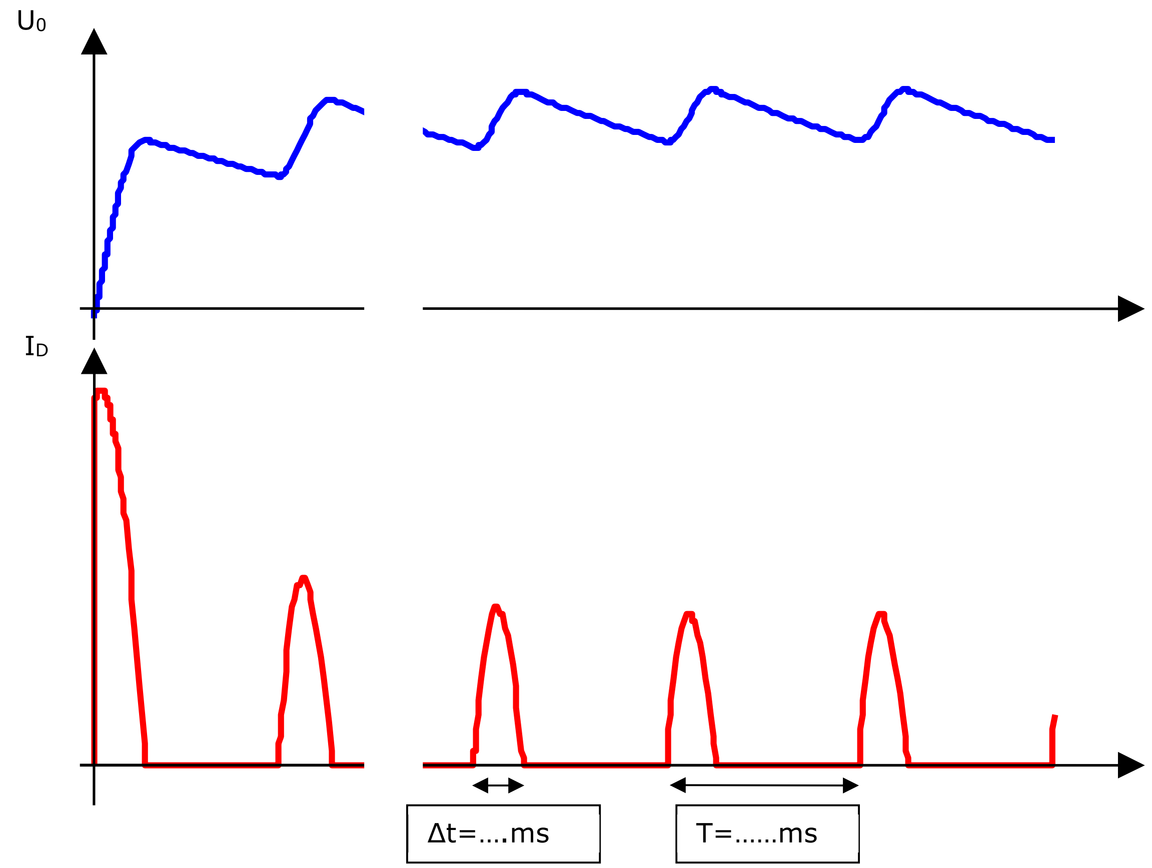

Tabela 2-5. Results of measurements. Electromotive force E_{RMS}=……….[V], transformer internal resistivity R_S=……..[Ω]

	$R_0 = R_{02}$= ....[Ω] C = C_1 =.........[μF] (small value		
Parameter	Calculations	Grapical/simulations	Measurements
U_{00AV} [V]			
U_{0MAX} [V]			
U_{0MIN} [V]			
$U_{0RIP(PP)}$ [V]			
U_{0AV} [V]			
U_{0RMS} [V]			
I_{0AV} [A]			
I_{DRMS} [A]			
I_{DMAX} [A]			
CF(I_D) MAX/RMS			
FF(I_D) RMS/|AV|			
Δt (czas przewodzenia diody) [ms]			
PF (wsp. mocy)			
P_{Rs} [W]			
I_{DSURGE} [A]			

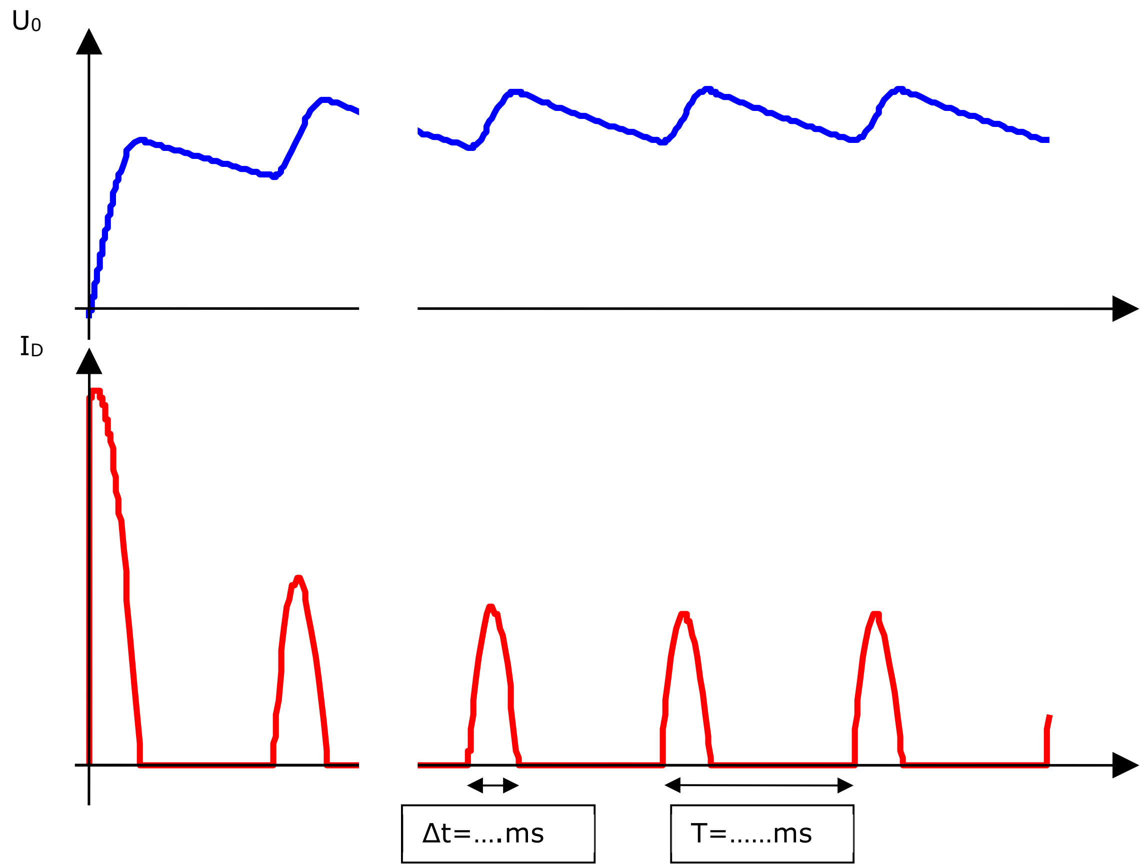

Tabela 2-6. Results of measurements. Electromotive force E_{RMS}=……….[V], transformer internal resistivity R_S=……..[Ω]

	$R_0 = R_{02}$= ....[Ω] $C = C_1+C_2$ =.........[μF] (small value		
Parameter	Calculations	Grapical/simulations	Measurements
U_{00AV} [V]			
U_{0MAX} [V]			
U_{0MIN} [V]			
$U_{0RIP(PP)}$ [V]			
U_{0AV} [V]			
U_{0RMS} [V]			
I_{0AV} [A]			
I_{DRMS} [A]			
I_{DMAX} [A]			
$CF(I_D)$ MAX/RMS			
$FF(I_D)$ RMS/|AV|			
Δt (czas przewodzenia diody) [ms]			
PF (wsp. mocy)			
P_{Rs} [W]			
I_{DSURGE} [A]			

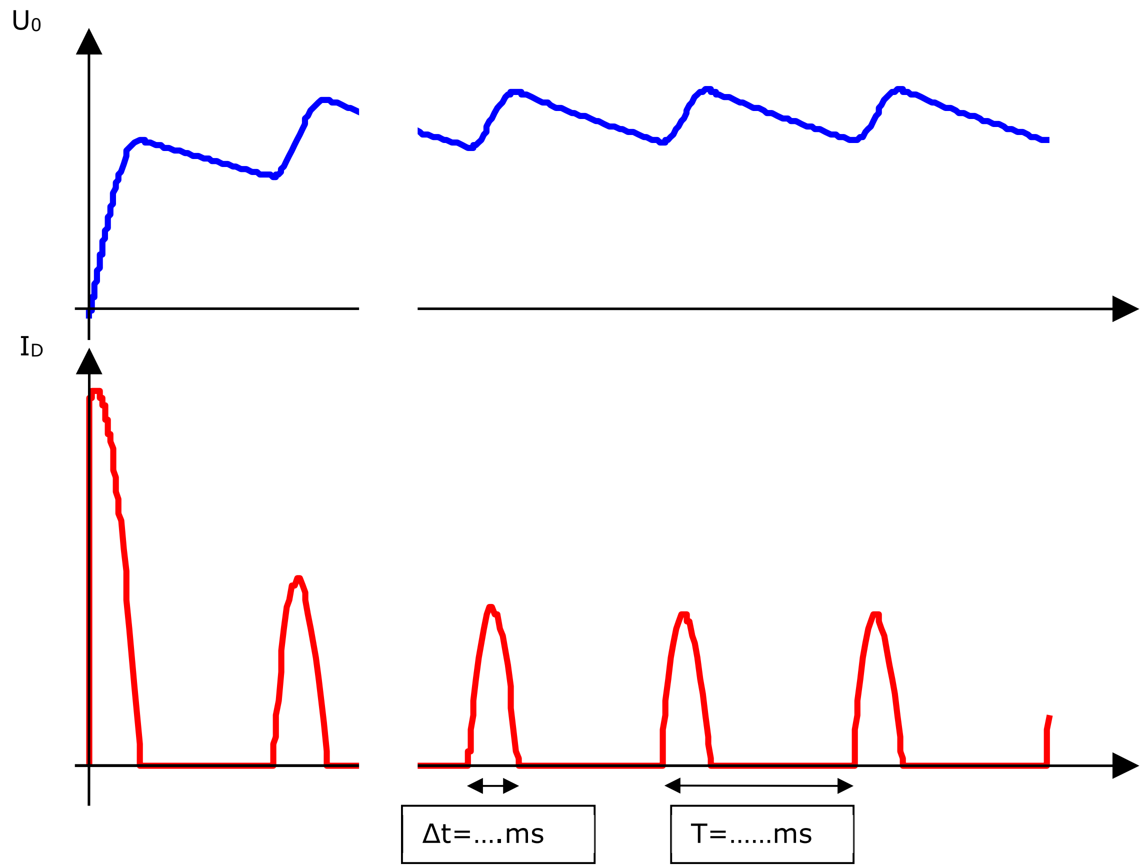

Tabela 3- Results of measurements. Electromotive force E_{RMS}=……….[V], transformer internal resistivity R_S=……..[Ω]

	No capacitor				C =........[μF] *(small value)*			C =........[μF]			C =........[μF] *(najmniejsza wartość)*			C =.........[μF]		
	R_0= …….[Ω]		R_0=......[Ω]		R_0 = ...[Ω]			R_0 = ... [Ω]			R_0 = ... [Ω]			R_0 = ... [Ω]		
Parameter	Calculations	Measurements	Calculations	Measurements	Analytic calculations	Graphical or comp. simulation	Measurements	Analytic calculations	Graphical or comp. simulation	Measurements	Analytic calculations	Graphical or comp. simulation	Measurements	Analytic calculations	Graphical or comp. simulation	Measurements
U_{00AV} [V]																
U_{0MAX} [V]																
U_{0MIN} [V]																
$U_{0RIP(PP)}$ [V]																
U_{0AV} [V]																
U_{0RMS} [V]																
I_{0AV} [A]																
I_{DRMS} [A]																
I_{DMAX} [A]																
$CF(I_D)$ MAX/RMS																
$FF(I_D)$ RMS/|AV|																
Δt (czas przewodzenia diody) [ms]																
PF (wsp. mocy)																
P_{Rs} [W]																
I_{DSURGE} [A]																