1 *Article*

2 # Improved Current Doubler Rectifier

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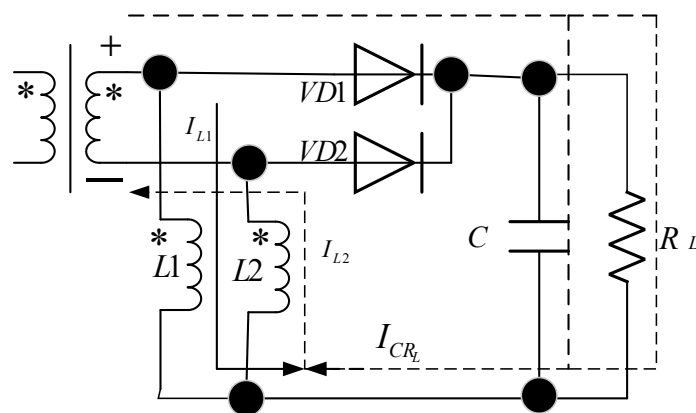5   Sofia 1000, Bulgaria; antchev@tu-sofia.bg
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8 **Abstract:**   It is widespread to examine and explain the functioning of the standard "Current
9 Doubler Rectifier" as strictly symmetrical according to the electrical current through the two
10 inductances. The present work challenges this consideration and proposes a new version of the
11 electrical circuit daigram where the current symmetry is improved. The proposed circuit is called
12 "Improved Current Doubler Rectifier".

13 **Keywords:** rectifier; current doubler; symmetry
14

15 **1. Introduction**

16   The advantages of the "Current Doubler Rectifier" compared to the "Voltage Doubler Rectifier"
17 for DC-to-DC converters are known [1]. There is also an option with transistors in the secondary side,
18 called "Synchronous current doubler rectifier" [2,3,4,5,6]. Other options use "coupled inductors"
19 [7,8,9]. Normally, the functioning of the "Current Doubler Rectifier", here called standard "Current
20 Doubler Rectifier", is examined in an established mode of operation [10,11,12]. In this mode, if there
21 is a voltage on the secondary coil of the transformer, the difference between this and the output
22 voltage is applied to one of the inductances and the current through it increases. At the same time
23 interval, on the other inductance is applied the output voltage, and the current through it decreases.
24 At zero voltage on the secondary coil of the transformer the currents through the two inductances
25 decrease. In this standard examining, the currents through both inductances have the same directions
26 at all time intervals, as they only increase or decrease. This consideration neglects the start-up process,
27 in which it turns out that the current through one of the two inductances has the opposite direction
28 to that of the established mode.

29

30 **Figure 1.** Diagram for clarifying the operation in the first cycle
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32   Figure 1 shows the principle diagram and the voltage and current indications during the first
33 operation cycle of the standard "Current Doubler Rectifier" after the converter has been started. It is
34 assumed that the voltage of the secondary coil of the transformer has the polarity shown in the figure.

35 It is seen that the current I_{L2} flows   through the inductance L_2 from the bottom to the top of the
36 circuit as it increases now and at any subsequent interval during which the polarity of the secondary
37 coil voltage is the same. During the pause and change of polarity, this current decreases but keeps its
38 direction. In this first cycle, the current I_{L1} flows as well, but in the opposite direction through the
39 inductance L_1 - from top to bottom of the circuit. This violates the symmetrical operation of the
40 standard "Current Doubler Rectifier". It is only when changing the polarity of the voltage of the
41 secondary coil in the next cycle, when the current I_{L1} will change its direction. An additional source
42 of asymmetry is the increase in the voltage of capacitor C after each operation cycle during the
43 startup process. For example, in the first cycle, the current I_{L2} is changing at the highest speed, as
44 the capacitor is discharged. In the next cycle, the current I_{L1}, besides starting from a negative value,
45 will also change at a slower speed as the capacitor is charged to some voltage from the first cycle, and
46 so on.

47   The difference in the two currents in the first cycle leads to different starting conditions. In
48 subsequent cycles during the startup process, some additional asymmetry causes increase in
49 capacitor C voltage after each cycle. As a result, during the time, at periodical operation the average
50 value of current I_{L1} remains lower than that of the current I_{L2} . As a result, the currents through
51 the two diodes VD1 and VD2 are different, as well as the current through the secondary coil of the
52 transformer has a direct current component. Similarly, if in the first operation cycle the polarity of
53 the voltage of the secondary coil is opposite to that shown in Figure 1, then the average current I_{L2}
54 value will be lower than that of I_{L1}. A difference in the average values of the two currents is noted in
55 the results of the experimental studies published in other articles, for example [6] (fig.14), [10] (fig.4),
56 [13] (fig.14), [14] (p.32). This difference remains in the case of "coupled inductors" - [9] (fig.9a). The
57 equalization of currents through the two inductances is paid attention in [15], where a "modified
58 current doubler rectifier" is proposed and the equalization is on the average values of the currents.

59   This article introduces a simplified modification of the standard solution called "Improved
60 Current Doubler Rectifier", which avoids, to a large extent, the above-mentioned disadvantages.
61 Comparative results of computer simulation and experimental research are presented.

62
63 **2. Computer simulation results**

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65   The above-mentioned conclusions about the difference in the average values of the currents
66 through the two inductances, due to the different operating conditions in the first cycle, are confirmed
67 in the present work with the help of computer simulation diagram done with PSIM program shown
68 in Figure 2. The observed values are indicated in the diagram and they are shown in Figure 3 and
69 Figure 4 for different inductance values. The indications of the values shown in the time diagrams
70 are seen in Fig. 2: I2, I3 – electric currents through the inductances; I1, VP1- electric current and
71 secondary coil voltage; I4, I5 – electric currents through the diodes; I6 - the sum of I2 and I3; I8 -
72 current through the capacitor; I1, V1 - current and voltage of the load.
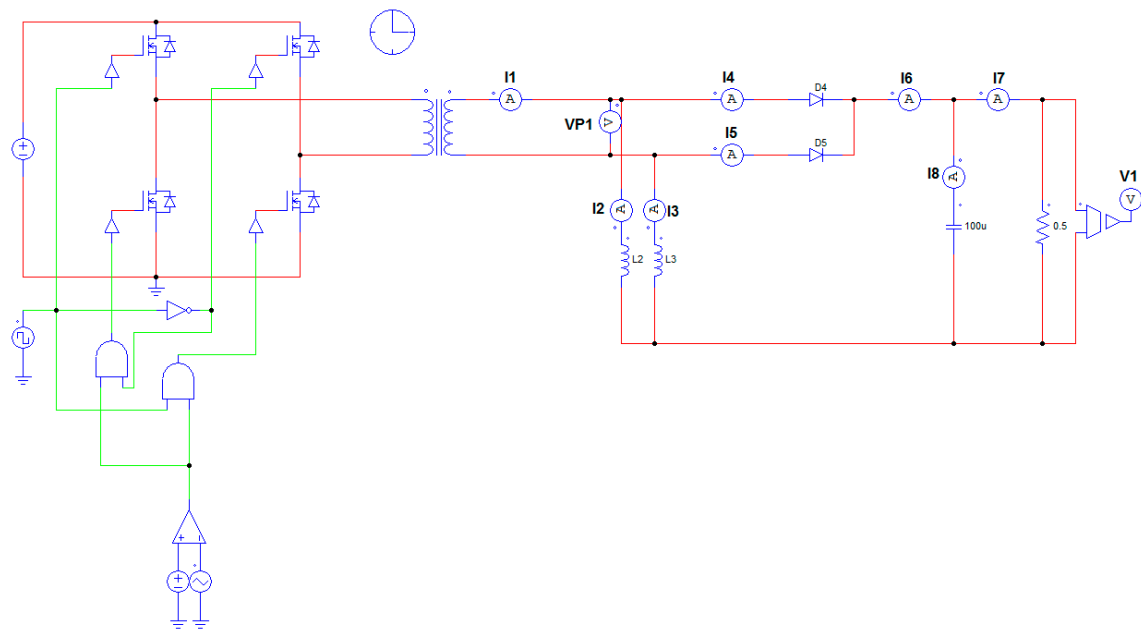
73
74   **Figure 2**. Computer simulation diagram of the standard "Current Doubler Rectifier".
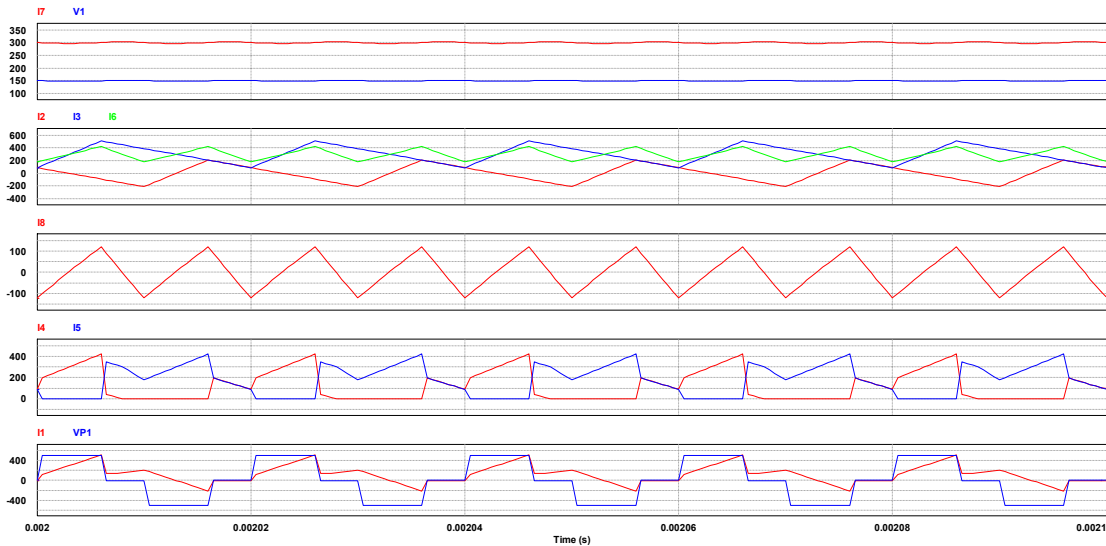

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76   **Figure 3.** Computer simulation results of a standard "Current Doubler Rectifier" with inductances $5\ \mu H$.
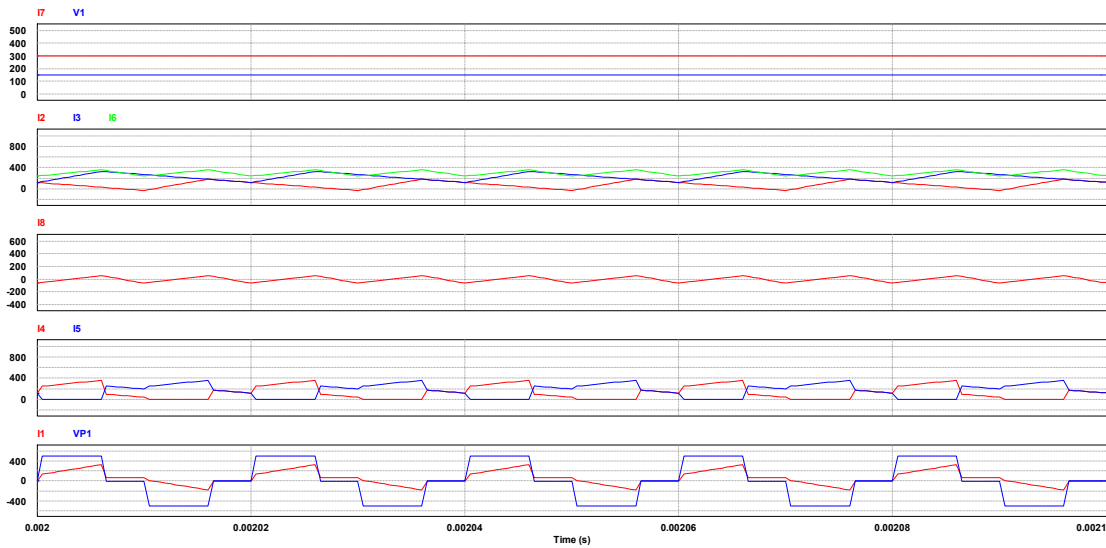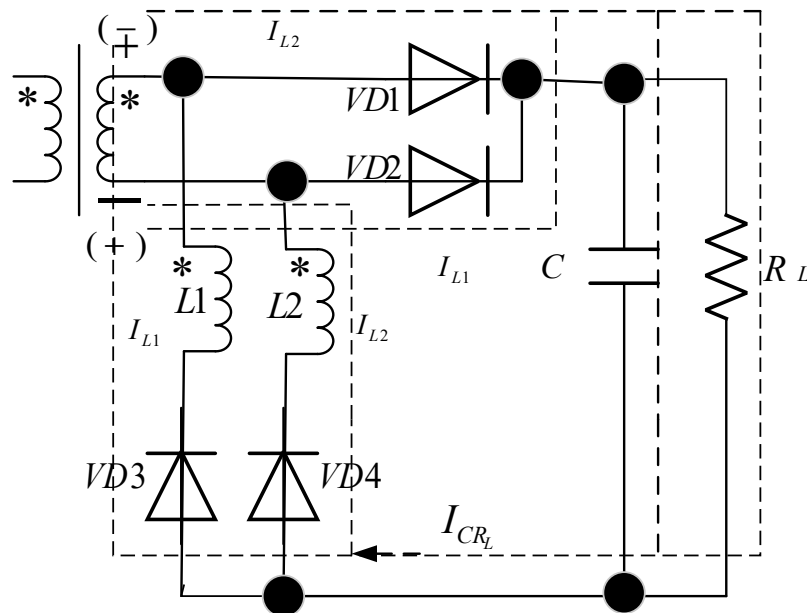

77
78   Figure 4. Computer simulation results of standard "Current Doubler Rectifier" with inductances $10\ \mu H$.

79   The comparison of the results of Figure 3 with those of Figure 4 shows that at a higher
80   inductances value the effect in question is less expressed, i.e. the difference in the values of the
81   average currents through them is smaller. Perhaps this is the reason why researchers did not notice
82   the difference in currents and did not pay attention to the start-up processes.
83   To avoid the asymmetry due to the first operating cycle, this article proposes the successive
84   connection of diodes to inductances, as the this circuit is called "Improved Current Doubler Rectifier"
85   – Figure 5. It shows that in the first operation cycle at the shown polarity of the voltage of the
86   secondary coil without brackets, electric current flows only through the inductance L_2 in direction
87   from the bottom to the top of the diagram. Due to the presence of $VD3$ in this first cycle, there is no
88   current flowing through the inductance L_1. When changing the polarity of the voltage in the second
89   cycle, shown in the figure in brackets, current will flow through the inductance L_1, in direction from
90   bottom to top. The diagram will have the same results if the first cycle corresponds to the polarity of
91   the voltage shown in brackets. In this way, the circuit becomes symmetrical with respect to the two
92   currents in their first cycle. From the diagram of Figure 5, it is seen that a single-phase bridge rectifier
93   is connected to the secondary coil of the transformer, as the inductances are being connected
94   successively with the diodes from the anode group $VD3, VD4$. It should be noted that only the
95   asymmetry due to the gradual charging of the capacitor C during the startup process remains.

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97

98   **Figure 5.** Diagram for clarifying the functioning of "Improved Current Doubler Rectifier".
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100   The operation of "Improved Current Doubler Rectifier" is checked with the computer simulation
101   diagram shown in Figure 6. The results are presented in Figure 7 and Figure 8 for the same values of
102   the two inductances corresponding to Figure 3 and Figure 4. Figure 7 and Figure 8 show almost
103   complete symmetry of the circuit in terms of currents through inductances, currents through the
104   diodes, and lack of a direct current component through the secondary coil of the transformer.
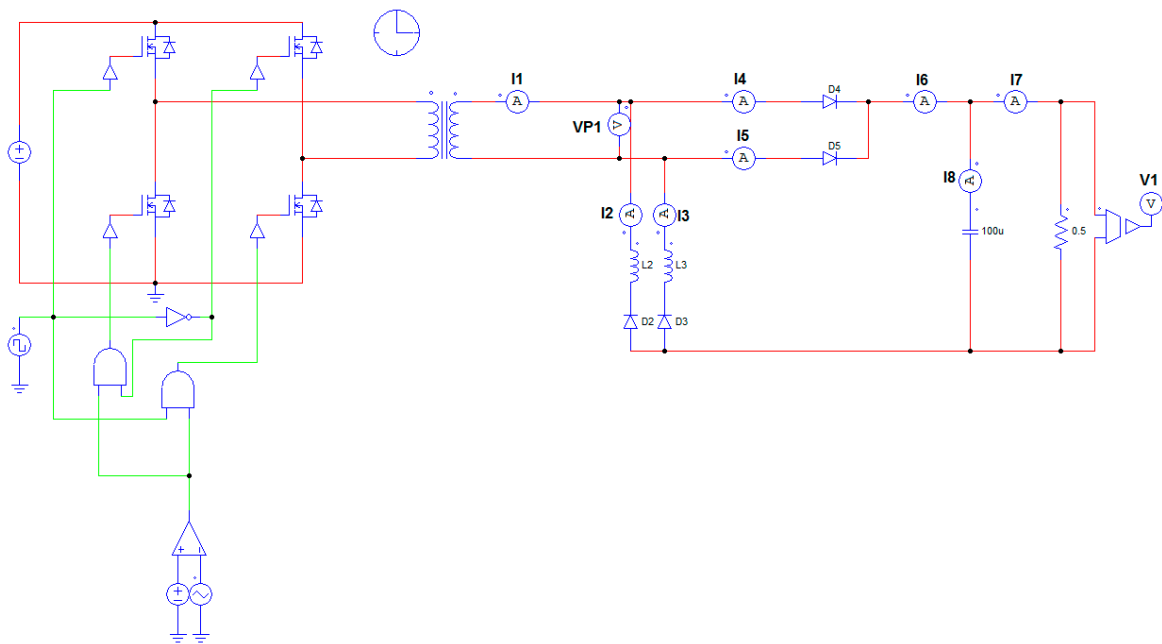
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Figure 6. "Improved Current Doubler Rectifier" computer simulation diagram.
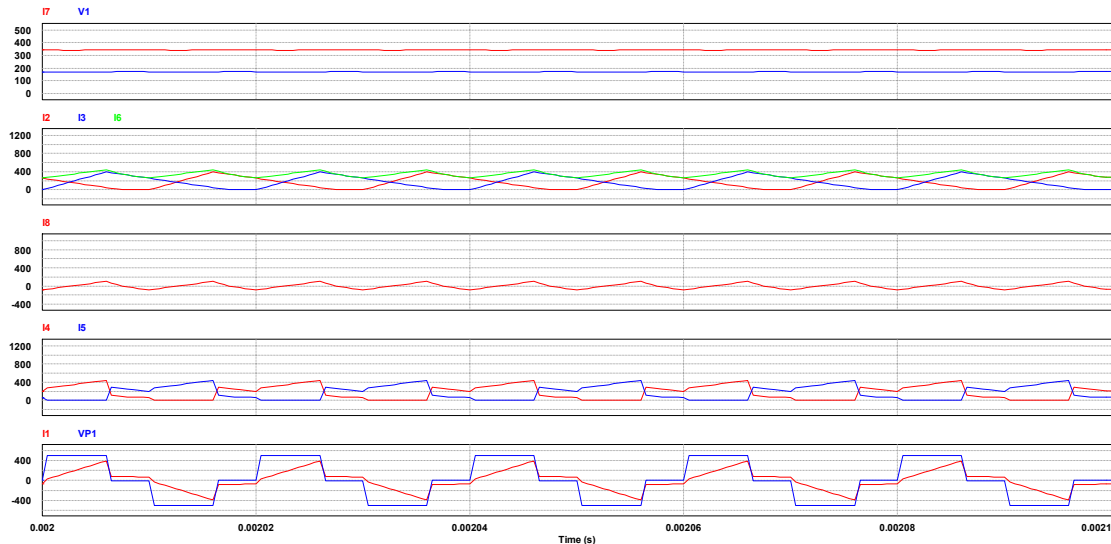
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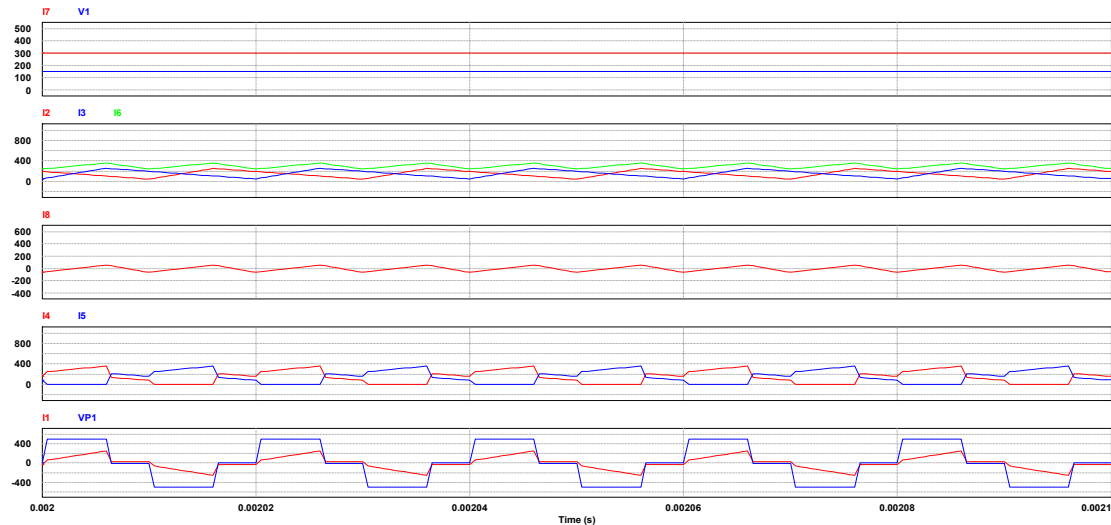**Figure 7.** Computer simulation results of "Improved Current Doubler Rectifier" with inductances $5\ \mu H$.

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Figure 8. Computer simulation results of "Improved Current Doubler Rectifier" with inductances $10\ \mu H$.

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112   **3. Experimental investigation**

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114   To investigate the start-up processes, a bridge DC / DC converter with a high-frequency
115   transformer has been implemented. This converter is powered by a voltage with a value $\approx 300V$,
116   obtained after rectification   the voltage of the power supply network. In the converter control
117   system, special measures are provided to ensure the symmetrical operation of the diagonally
118   connected transistors in both half periods. In the first part of the experiment, a standard "Current
119   Doubler Rectifier" of Figure 1 is connected in the secondary side at inductances value of $21\mu H$. The
120   values of the two inductances are specifically selected to be equal, and the measurement is done with
121   an electronic RLC meter. Figure 9 and Figue 10 show oscillograms from the initial run experiment at
122   different time scales. When monitoring the oscillogram of the voltage on the secondary coil of the
123   transformer, the active end of the voltage probe on the oscilloscope's first channel is connected to the
124   anode of $VD2$ diode, and the ground - to the anode of diode $VD1$. The currents are monitored by a
125   current probe, connected to the second channel at a 100mV / A scale. The probe is connected so, that
126   the positive direction of the current through it is from the end to the beginning of each inductance.
127   On all the oscillograms shown below, the voltage scale of CH1 is 10V / div, and the current scale of
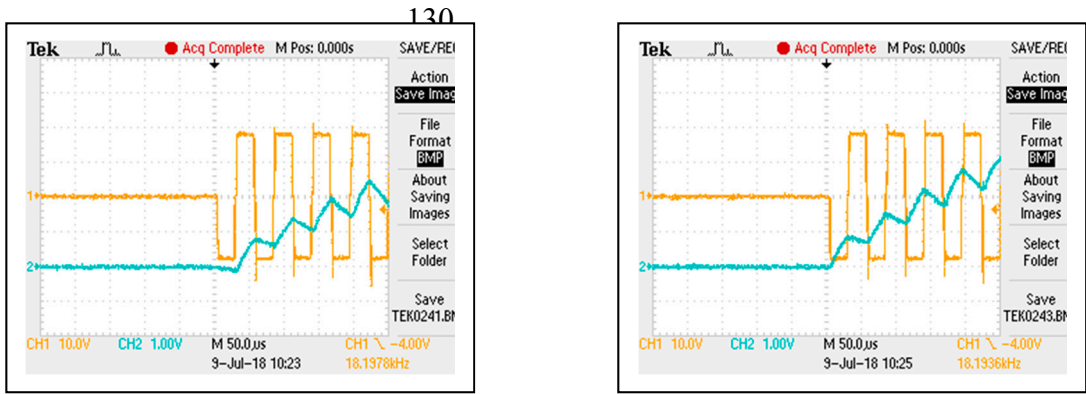128   CH2 is 10A / div.

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130

142   a   b

143   **Figure 9.** Horizontal axis scale $\frac{50\mu S}{div}$: a – voltage of the secondary coil of the transformer and current
144   through inductance L_1, b - voltage of the secondary coil of the transformer and current through inductanceL_2.

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146

157

158   a   b

159   **Figure 10.** Horizontal axis scale $\frac{100\mu S}{div}$: a – voltage of the secondary coil of the transformer and current
160   through inductance L_1, b - voltage of the secondary coil of the transformer and current through inductance L_2.
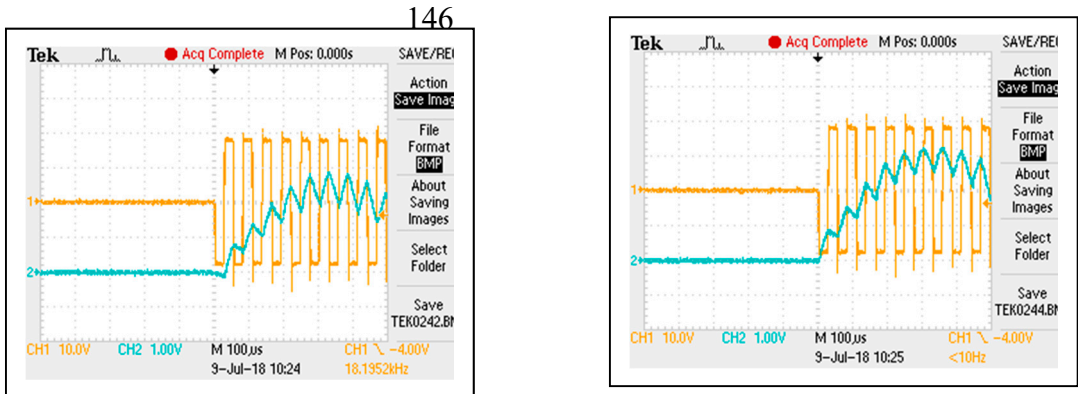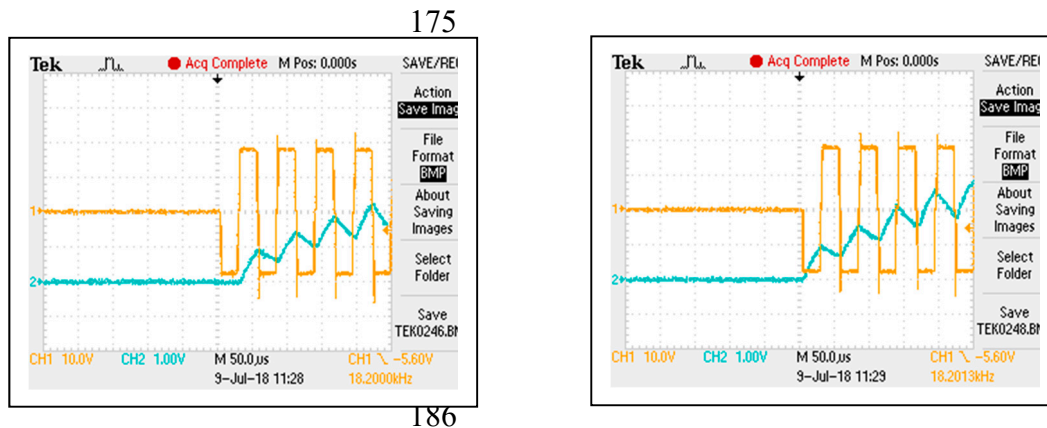
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162   From the comparison of Figure 9a and Figure 9b can be seen the difference in the first operation cycle. At
163   the described connection of the first channel voltage probe, the first cycle corresponds to the negative voltage of
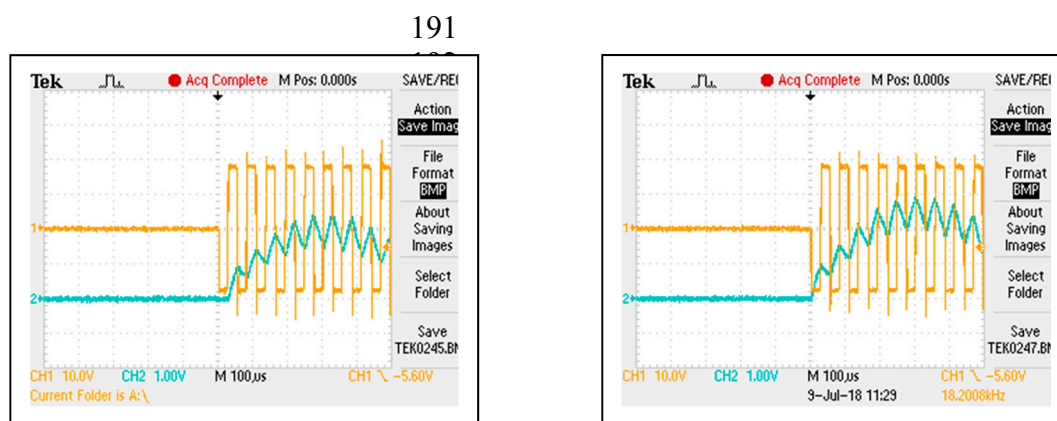
164   the anode $VD2$ to the anode of $VD1$ (therefore positive voltage of anode of $VD1$ to the anode of $VD2$). At this
165   first cycle the current through L_1 flows in the opposite direction and in the second cycle starts from a negative
166   value that is -2A. In the first cycle the current through L_2 starts from zero value.
167   From the comparison of Figure 10a and Figure. 10b can be seen the difference in the maximum values of
168   currents during the start-up process - for the inductance L_1 the maximum value is 28A and for the inductance
169   L_2 - 33A. Therefore, the difference in the maximum values is 5A.
170   In the second part of the experiment, in the secondary side is connected the so-called "Improved Current
171   Doubler Rectifier" only by adding the two diodes $VD3, VD4$ of the anode group in Figure 5, at the same
172   inductances value $21\mu H$ Figure 11 and Figure 12 show oscillograms from the start-up processes in different
173   time scales. The position and scale of the voltage and current probes is unchanged.

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187   a   b
188   **Figure 11**. Scale on horizontal axis $\frac{50\mu S}{div}$: a - voltage of the secondary coil of the transformer and current
189   through inductance L_1, b - voltage of the secondary coil of the transformer and current through inductance L_2.
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191

202

203
204   a   b
205   **Figure 12**. Scale on horizontal axis $\frac{100\mu S}{div}$: a - voltage of the secondary coil of the transformer and current
206   through inductance L_1, b - voltage of the secondary coil of the transformer and current through inductance L_2.
207
208   From the comparison of Figure 11a and Figure 11b it is seen that there is no current flowing through the
209   inductance L_1 in the opposite direction during the first cycle (unlike Figure 9a). During the second cycle this
210   current starts at zero value. In the first cycle, the current through L_2 starts from a zero value as it is in Figure
211   9b.
212   From the comparison of Figure 12a and Figure 12b the difference in the maximum current values during
213   the start-up process is visible - for the inductance L_1 the maximum value is 24A and for the inductance L_2 28A.
214   Therefore, the difference in the maximum values is 4A and it is reduced compared to the first case. Although
215   smaller, there is some asymmetry in the currents, due to the gradual increase in capacitor C voltage as it was

216   described in the introduction.
217
218   **4. Conclusions**
219   The results of the researches through computer simulation and these of the experimental studies confirm
220   the original theoretical examination and prove the advantages of the offered in the present work "Improved
221   Current Doubler Rectifier", namely: improving the symmetry of the currents through the two inductances (at
222   their fully equal values and symmetric control of the converter in the primary side); lack of a direct current
223   component in the secondary coil of the transformer. These advantages are achieved by a simple modification of
224   the standard circuit. The advantage, however, is at the expense of a certain disadvantage - the increased number
225   of "Improved Current Doubler Rectifier" diodes. The proposed circuit could be developed and tested though
226   synchronous current rectification in the secondary side, similar to the "Synchronous current doubler rectifier".
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228   **Conflicts of Interest:** The author declare no conflict of interest.

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