Approximate Non-linear Models for Autotransformers and Switching

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ABSTRACT: *The Alternative Current voltages have discrete regulation and the regulation is achieved by power electronic converters based on autotransformers and switching. We have used vector analysis and measurements in autotransformer discrete voltage regulator. These regulators change to approximated non-linear models with change of input voltage and various angles in the semiconductor switches.*

Keywords: Vector Analysis, Vector Measurements, Voltage Regulator, Semiconductor Switch, Thyristor

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1. Introduction

In Figure 1 the equivalent circuit of an autotransformer discrete AC voltage regulator (ADACVR) with four terminals and four controllable semiconductor switches (CSS) is shown.

The equivalent circuit corresponds to the approximate model as the losses in the autotransformer core are not considered, the semiconductor switches are accepted for ideal and the RC groups, which shunt the thyristors in the semiconductor switches, are not taken into account. The adopted control algorithm is connected with switching at random moment as the commutation is always performed between two neighbouring semiconductor switches [1, 2].

The feeding with control pulses is suspended to the thyristor switch, which will be turned off (the switch remains conductive until the natural commutation of the thyristors inside it), and the other switch starts to be fed with control pulses.

The equivalent circuit of the precise model and its mathematical description are presented in details in literature [3,4].

The aim of the current work is the comparative research into the loading (the semiconductor switches, the autotransformer windings) by vector analysis and vector measurements of the quantities during the commutation process at different character of the load – R, RL and RC and different commutation angles.

2. Analysis

In this paper a vector analysis at low values of the input voltage of ADACVR is conducted. In this case, the switch K_4 is turned off and the switch K_3 is switched on (Figure 1)

At the same time, at certain angles φ of the commutation process, it is possible r_4 and L_4 (Figure 1) to be connected in short circuit through two thyristors, one from the switch K_4 and one from the switch K_3 respectively, for the time until the natural commutation of the switch K_4 occurs. This mode assumes an overload regime of the fourth section of the autotransformer and the two connected in series thyristors from the switches K_4 and K_3, when they are triggered

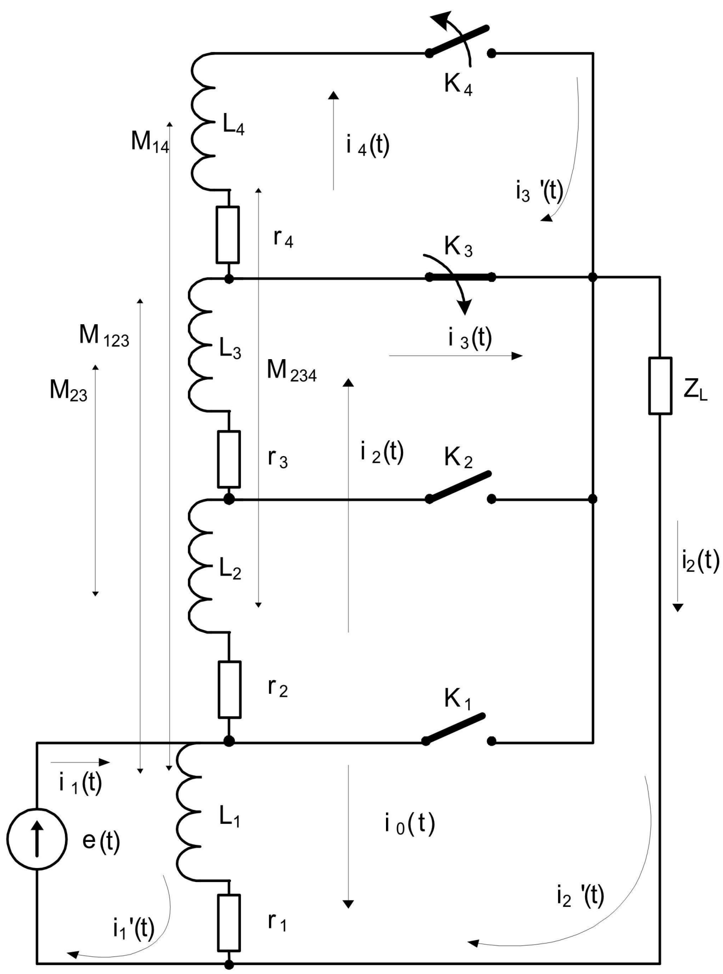
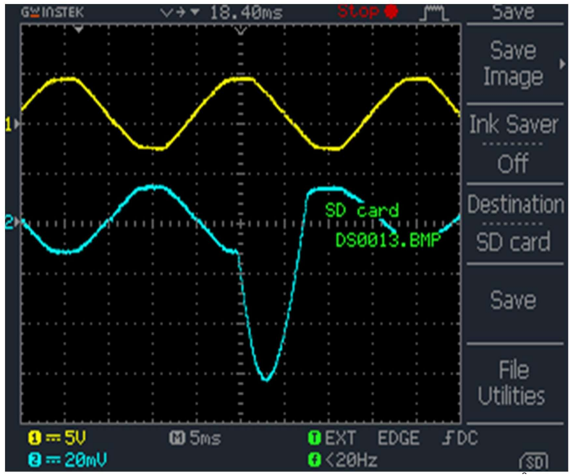
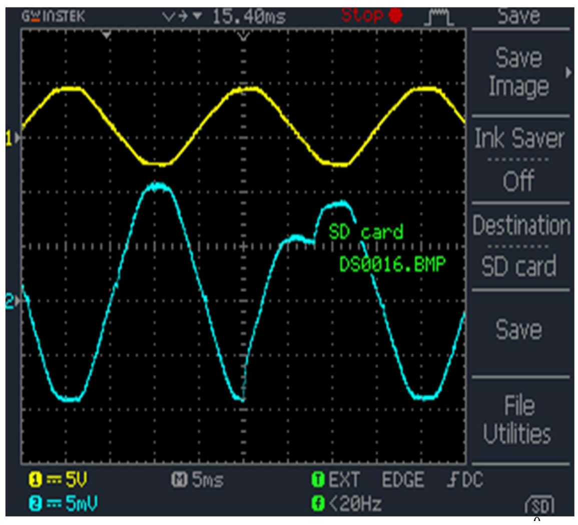


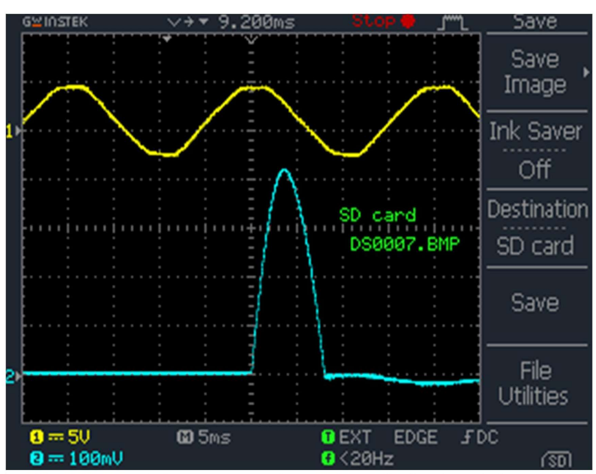
Figure 1. Equivalent Circuit of an ADACVR with Four CSS at Input Voltage Change



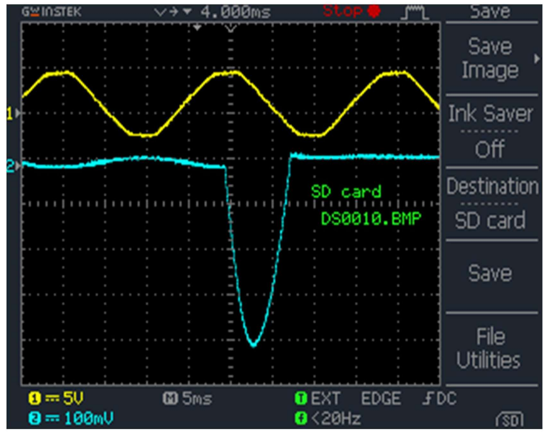
a) Oscillogram of the input current $i_1(t)$ at $\varphi = 270^0$



b) Oscillogram of the output current $i_2(t)$ at $\varphi = 270^0$

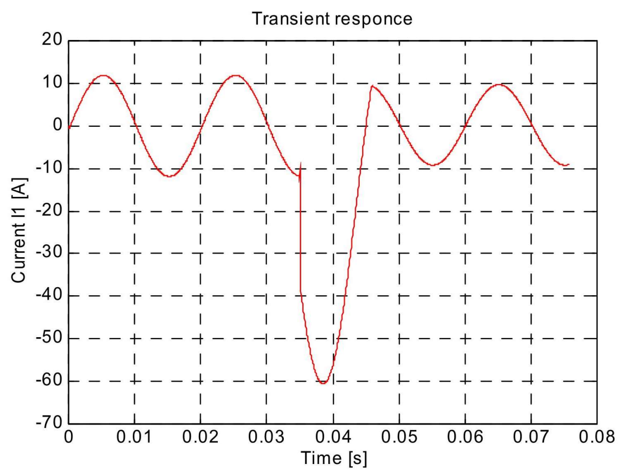


c) Oscillogram of the current through switch κ_3 - i_3(t) at $\varphi = 270^0$

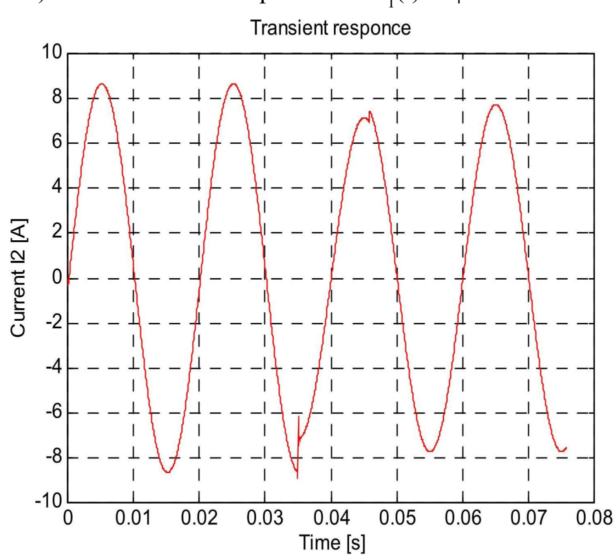


d) Oscillogram of the current through switch κ_4 - i_4(t) at $\varphi = 270^0$

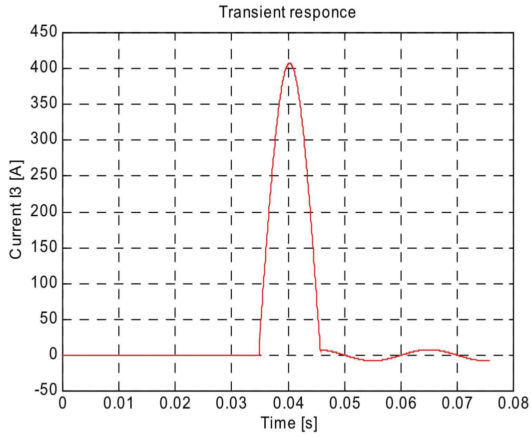
Figure 2. Experimental oscillograms of the currents of the ADACVR for R load and commutation angle $\varphi = 270^0$



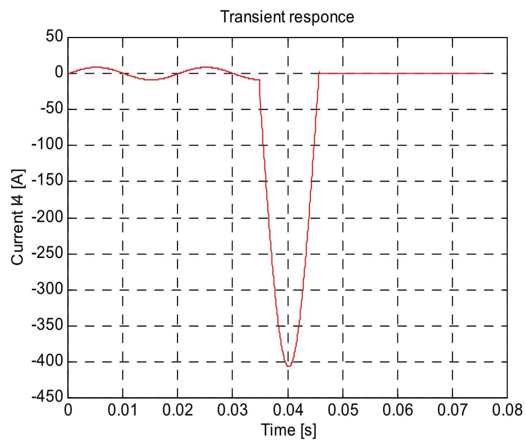
a) Simulation of the input current $i_1(t)$ at $\varphi = 270^0$



b) Simulation of the output current $i_2(t)$ at $\varphi = 270^0$

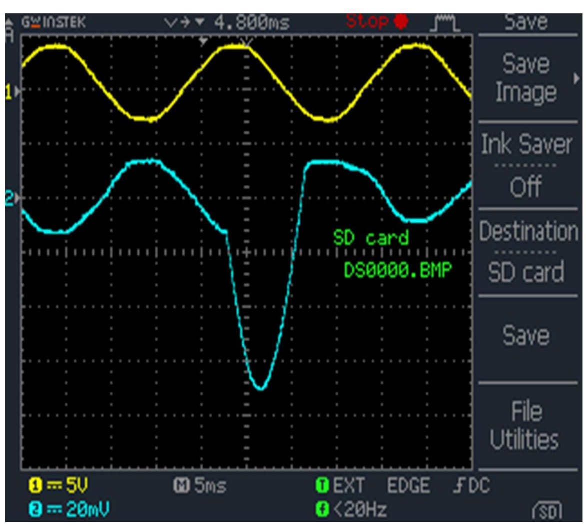


c) Simulation of the current through switch κ_3 - $i_3(t)$ at $\varphi = 270^0$

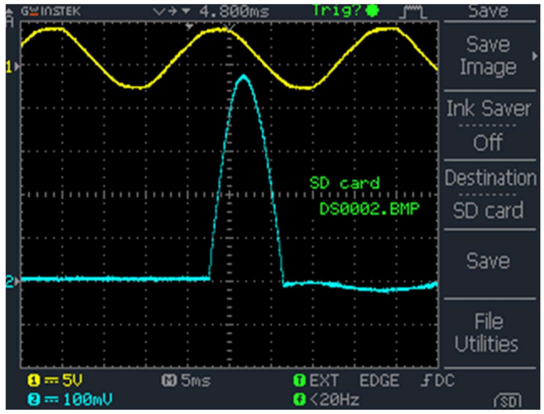


d) Simulation of the current through switch κ_4 - $i_4(t)$ at $\varphi = 270^0$

Figure 3. Computer simulation of the currents of the ADACVR for *R* load and commutation angle $\varphi = 270^0$

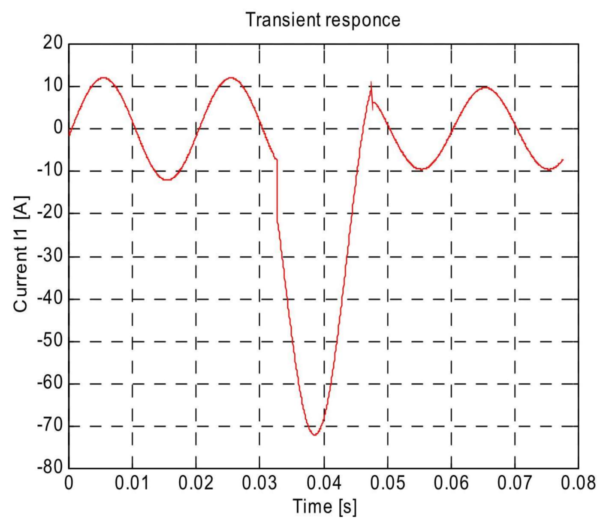


a) Oscillogram of the input current $i_1(t)$ at $\varphi = 225^0$

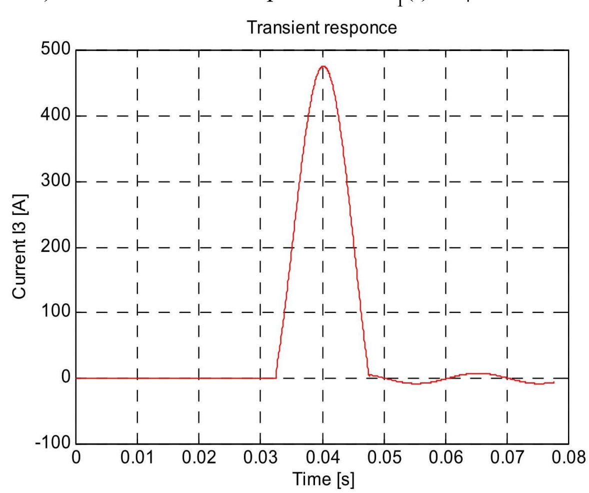


b) Oscillogram of the current through switch κ_4 - $i_3(t)$ at φ =225^0

Figure 4. Experimental oscillograms of the currents of the ADACVR for RL load and commutation angle φ =225^0

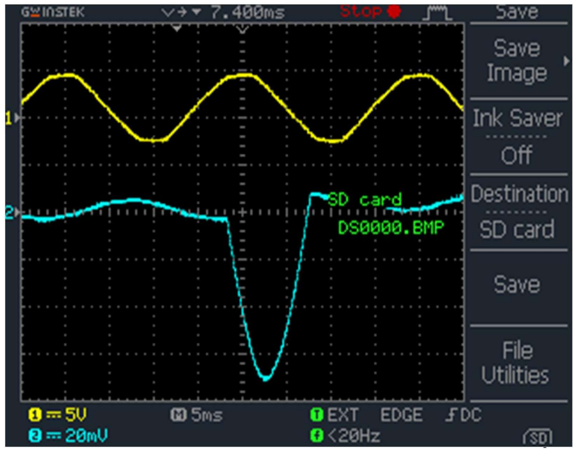


a) Simulation of the input current $i_1(t)$ at φ =225^0

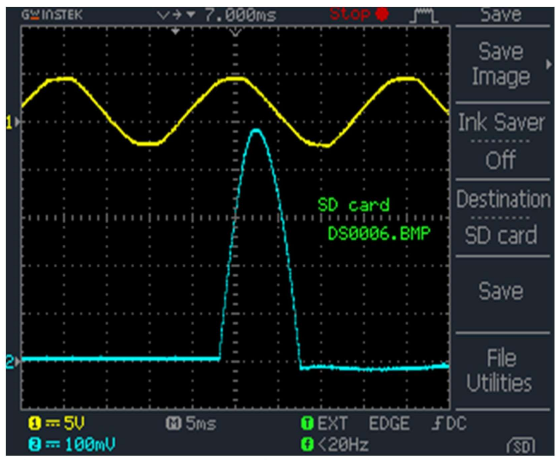


b) Simulation of the current through switch κ_3 $i_3(t)$ at φ =225^0

Figure 5. Computer simulation of the currents of the ADACVR for RL load and commutation angle φ =225^0

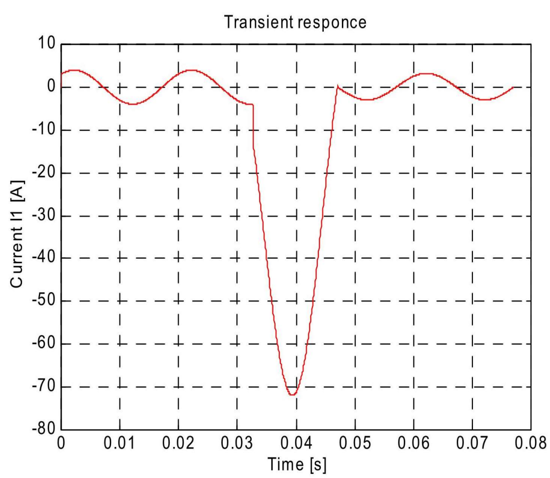


a) Oscillogram of the input current $i_1(t)$ at $\varphi = 225^0$

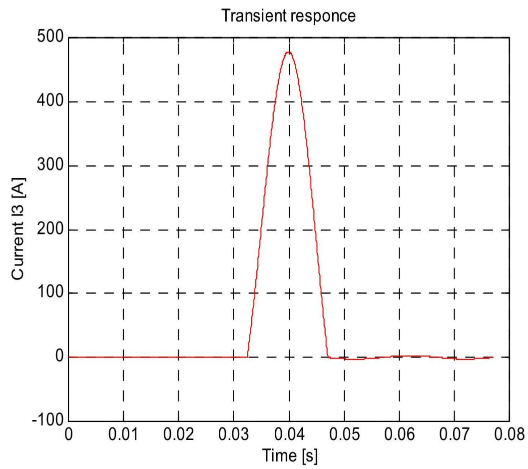


b) Simulation of the current through switch κ_3 - $i_1(t)$ at $\varphi = 225^0$

Figure 6. Experimental oscillograms of the currents of the ADACVR for RC load and commutation angle $\varphi = 225^0$



a) Simulation of the input current $i_1(t)$ at $\varphi = 225^0$



b) Simulation of the current through switch κ_3 - $i_1(t)$ at φ =225^0

Figure 7. Computer simulation of the currents of the ADACVR for RC load and commutation angle φ = 225^0.

In case of an active load (R-load) and commutation angle φ = 270^0, the results from the experimental oscillograms and the computer simulations with the programme AVTO in MATLAB integrated environment, are presented in Figure 2 and Figure 3. When we have RL and RC loads, the development of the commutation process can be followed in Figure 4 and Figure 5, Figure 6 and Figure 7 respectively. The experimental oscillograms and simulations are taken at commutation angle φ = 225^0.

The received experimental data for a concrete regime (closed switch K_4 and opened switch K_3) are shown in Table 1. The analytical data in the table are very close to those from the analysis of the precise model [4,5,6]. The numerical values from the simulations with the approximate model of the voltage regulator differ with average deviation 0, 9% (minimum deviation 0,07% and maximum deviation 2,83%) from those, received by a simulation with the precise model.

Table 1

Load	***Experimental data***			***Computer simulations***		
	I_1	I_2	U_2	I_1	I_2	U_2
	A	A	V	A	A	V
R	8,45	6,16	219	8,3965	6,1205	218,6
RL	9,75	7,03	219,9	8,5181	6,2016	217,8
RC	2,85	2,15	220,3	2,8034	2,1421	222,6

Note: The loads for the experiments and the simulations, shown in the table, are as follows:

R load - 35,7Ω;

RL load - R-35,7Ω, L-1,76H (connected in parallel);

RC load - R-61,78Ω, C-38,09μF (connected in series).

In Table 2 the vector quantities of the currents and the voltages of the autotransformer discrete regulator from the equivalent circuit in Figure 1 are presented.

3. Conclusion

A vector analysis and vector measurements of the quantities, referred to the commutation and the regimes in a power semicon ductor converter with discrete regulation of the input AC voltage magnitude to the joined consumers have been conducted. A precise and approximate (with certain simplifications) models have been examined at different angles for the commutation process and for different loads.

Both results – from the experiments and from the computer simulations, show a very good match of the obtained results.

A programme AVTO in MATLAB is developed, and it allows visualization of the computer simulations as well as examination of the discrete AC voltage regulator with different loads and parameters of the commutation processes.

Table 2

Load	***Results from vector measurements***		
	$\dot{I}_1$	$\dot{I}_2$	$\dot{U}_2$
	A	A	V
R	$8{,}45e^{-j0{,}08}$	$6{,}16e^{-j0{,}06}$	219
RL	$9{,}75e^{-j0{,}14}$	$7{,}03e^{-j0{,}12}$	$219{,}9e^{j0{,}06}$
RC	$2{,}85e^{j0{,}89}$	$2{,}15e^{j0{,}92}$	$219e^{-j0{,}01}$

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