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PRACTICAL REALIZATION OF FUZZY CONTROLLER

Summary. The aim of the paper is to investigate some possibilities of implementation fuzzy controller with use of 16-bit microcontroller. The authors used known classical controlled rectifier and RL load as the object of investigation. The control unit was based on Hitachi microcontroller H8/3048, popular for industrial applications. The synchronization and gate pulses are transmitted and converted by CPLD between power circuit and ITU of microcontroller. The ITU carries out the algorithm of generated gate pulses using synchronization signals. The current controllers: fuzzy logic and classical PI were implemented. Some details about process of fuzzyfication, interference and defuzzyfication are also presented. The obtained measurements include current waveforms for fuzzy and PI controllers with some additional signals gained from microcontroller by D/A converter. The experiment points out that 16-bit microcontrollers are useful also for fuzzy algorithms.

PRAKTYCZNA REALIZACJA REGULATORA ROZMYTEGO

Streszczenie. Celem artykułu jest przedstawienie możliwości realizacji regulatora rozmytego za pomocą 16-bitowego mikrokontrolera. Jako obiekt sterowania autorzy wybrali klasyczny prostownik tyrystorowy z obciążeniem typu RL. Układ sterowania bazuje na mikrokontrolerze Hitachi H8/3048, popularnym w wielu zastosowaniach przemysłowych. Sygnały synchronizacji i sterujące zostały dopasowane do wymagań sterownika i układu wyzwalania przekształtnika za pomocą matrycy programowalnej CPLD. Do sterowania prostownika wykorzystano układ komparatorowo-licznikowy ITU, znajdujący się w mikrokontrolerze. Zaimplementowano regulator rozmyty oraz regulator PI. W artykule przedstawiono szereg szczegółów dotyczących procesów przetwarzania w regulatorze rozmytym: rozmywania, procesu decyzyjnego i antyrozmywania. W końcowej części artykułu zamieszczono pewne wyniki pomiarów dla obu regulatorów, pokazujące poprawność działania. Wewnętrzny przetwornik C/A mikrokontrolera umożliwił także przedstawienie pewnych wewnętrznych sygnałów regulatorów. Eksperyment pokazał, że możliwe jest zastosowanie tej klasy mikrokontrolera do realizacji regulatora rozmytego dla takich obiektów.

1. INTRODUCTION

The modern industry requires control systems not only with high degree of accuracy but also with good dynamic performance and robust for changing parameters of system. Traditional control schemes, such as proportional plus integral types, have included in their mathematical models gain constants which must be determined by calculations and trial to improve obtain results. Once their constants have been determined, the controllers perform very well but only under a small set of conditions. It is shown that a fuzzy logic controller is robust, operates in real time, and accommodates some nonlinearities [1], [2]. Fuzzy control is used not only in power electronics and drives [5] but mostly in industrial processes which are difficult to present with the use of mathematical models.

2. MOTIVATION

The aim of the paper is to investigate some possibilities of implementation fuzzy controller with use of 16-bit microcontroller. The most important thing for the authors is to check some difficulties and problems in practical realization of fuzzy algorithms.

3. CONTROL UNIT

For solving this problem the authors used laboratory setup with well known classical controlled rectifier and RL load as the object of investigation.

We chose typical Hitachi 16-bit microcontroller H8/3048F which was designed for industry applications, as the heart of control unit [3]. Its CPU has a 32-bit internal architecture with optimized instruction set. Sixty two instructions with:

- 8/16/32-bit data transfer, arithmetic, and logic instructions,
- signed and unsigned multiply instructions (8 bits x 8 bits, 16 bits x 16 bits),
- signed and unsigned divide instructions (16 bits ÷ 8 bits, 32 bits ÷ 16 bits),
- bit accumulator function,
- bit manipulation instructions with register-indirect specification of bit positions,

allow to built compact program for different tasks.

The most important on-chip supporting functions include 128kB FLASH, 4kB RAM, 16-bit integrated timer unit (ITU), programmable timing pattern controller (TPC), A/C converter, D/A converter, serial communication interfaces and watchdog timer [3]. All these peripherals make 3048F good solution for control in power electronics.

Programmable integrated timer unit (ITU) can be used for control PWM inverters as well for line-commutated converters. The ITU consists of five 16-bit timer channels which can work independently or connected together. There are two programmable input/output pins for each channel and eight possible counter clock sources (4 internal clocks and 4 external clocks). The most important operating modes are:

- waveform output by compare match,
- input capture function on chosen edge,
- PWM mode,
- reset-synchronize PWM and complementary PWM mode for control of 3-phase PWM inverters,
- synchronization of some of channels.

The microprocessor control unit is presented in fig. 1. The control unit was designed for softstart converters, but some circuits are universal for all line-commutated converters, so it is possible to use it for control of 6-pulse rectifier. The synchronization and gate pulses are converted and transmitted by CPLD between power circuit and ITU of microcontroller. The ITU carries out the algorithm of generated gate pulses using three synchronization signals. The delay angle α_z is generated by a current controller.

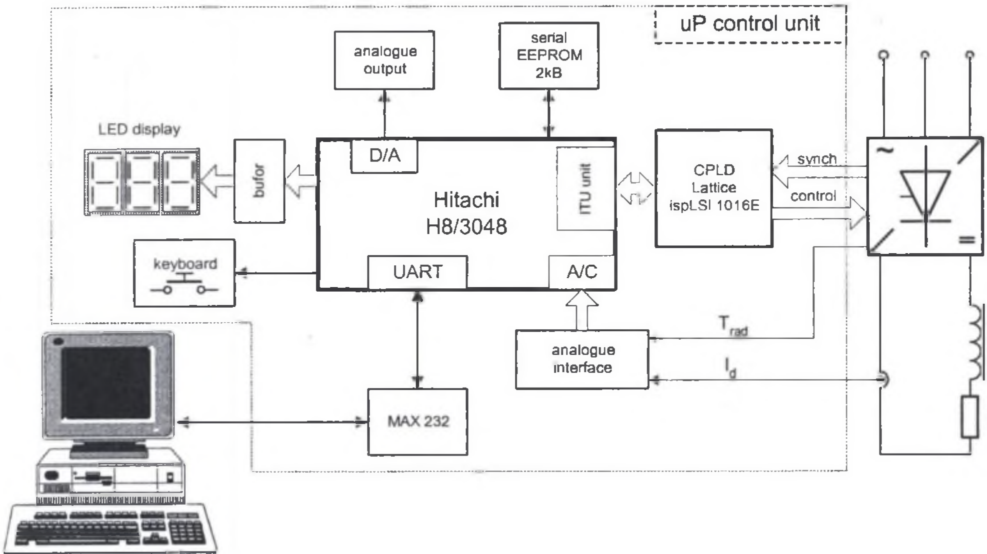

Fig. 1. Block diagram of control unit
Rys. 1. Schemat blokowy układu sterowania

Some details about control unit are presented at photo in fig. 2. Its upper part consists of synchronization circuits with transoptors which separate high voltages from microprocessor system.

Central part consists of the microprocessor system with input/output interface for user: keyboard and LED display. It is possible to show some measured and reference value.

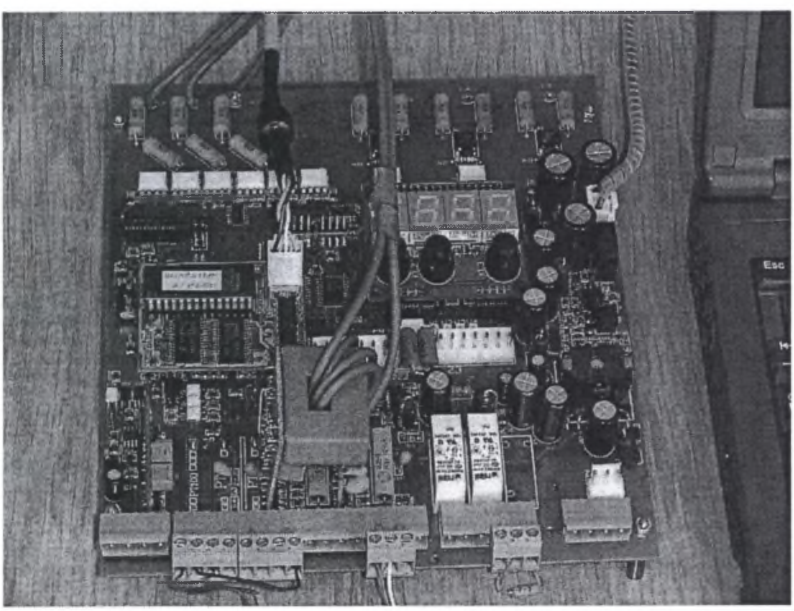

Fig. 2. Photo of the control unit used in experiment
Rys. 2. Zdjęcie sterownika wykorzystanego w eksperymencie laboratoryjnym

In down part we can see Hall effect sensor (LEM) for DC current measurements which allows to measure current in a range 0 – 12,5 A. The output signal of LEM is converted into voltage signal and after 10-bit A/D conversion, used as a feedback for current controller. Reference current value is set by the keyboard.

The current controllers: PI and fuzzy logic were implemented in the microcontroller. The current control algorithm is operated at 1 kHz frequency in the both solutions. The FL speed controller is of standard structure. An integrator antiwindup mechanism is included within the PI controller. The authors used Euler's method for numerical integration.

Table 1

FL current controller rule base

Δε \ ε	LN	SN	Z	SP	LP
LN	LN	LN	LN	LN	SP
SN	LN	LN	SN	Z	LP
Z	LN	SN	Z	SP	LP
SP	LN	Z	SP	LP	LP
LP	SN	LP	LP	LP	LP

For FL controller *current error* and *change of current error* are used as a linguistic variables. The output of the controller is the incremental delay angle command $\Delta\alpha_z$. The linguistic fuzzy variable *current error* (ε) has five sets: negative large, negative small, zero, positive small, positive large. All membership functions are triangular or trapezoidal shape because they are easy to handle with the microcontroller. The similar situation is with the linguistic fuzzy variable *change of current error* ($\Delta\varepsilon$). Implemented FL control rule base consists of 25 rule and is presented in table 1.

All calculations are obtain using fixpoint operations, so first step is normalization of fuzzy variables ε and $\Delta\varepsilon$. The range for current error is:

$\varepsilon=0...4000$ [in bits]
and for change of current error is:
$\Delta\varepsilon=0...8000$ [in bits]
with zero points in the middle of ranges.

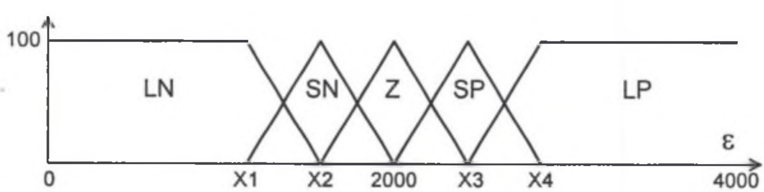

Fig. 3. Membership function of current error ε
Rys. 3. Funkcja przynależności dla uchybu prądu ε

Process of fuzzyfication generates vector of five variables (for both linguistic fuzzy variables) which point degree of membership functions (LN, SN, Z, SP, LP). These degree can change in range (0...100) - fig. 3 and the value can be calculated using piece linear functions which use only operations of multiplication and division – table 2. The regions for membership functions X1, X2, X3, X4 were set experimentally and can be changed before compilation of program. The same situation is with change of current error but values of regions are different - Y1, Y2, Y3, Y4.

Table 2

Values for membership functions from fig. 3

ε_n	LN	SN	Z	SP	LP
0-X1	100	0	0	0	0
X1-X2	$100\frac{\varepsilon_n - X1}{X2 - X1}$	$100\frac{X2-\varepsilon_n}{X2-X1}$	0	0	0
X2-2000	0	$100\frac{\varepsilon_n - X2}{2000-X2}$	$100\frac{2000-\varepsilon_n}{2000-X2}$	0	0
2000-X3	0	0	$100\frac{\varepsilon_n - 2000}{X3-2000}$	$100\frac{X3-\varepsilon_n}{X3-2000}$	0
X3-X4	0	0	0	$100\frac{\varepsilon_n - X3}{X4-X3}$	$100\frac{X4-\varepsilon_n}{X4-X3}$
X4-4000	0	0	0	0	100

The both vectors are used for fuzzy interference engine based on table 1. Depend on value of fuzzy variables: ε and $\Delta\varepsilon$ the interference engine gives 1-3 different output fuzzy rules from 25 included in the controller rule base - table 1. The fuzzyfication is the final phase of fuzzy reasoning. The first step is an aggregation process that produces the final fuzzy regions. This region is then decomposed using in this project the center of gravity method [1]. The authors used singelton functions for defuzzyfication - fig. 4.

The calculations can be done by microcontroller on line because of very simple membership functions for output. FL controller is of the incremental type. Therefore the previous output u_{n-1} is added to the current output from FLC. It was measured that processing time of FL controller was reduced to approximately 300 μs, so 700 μs CPU has for other tasks, for example operations connected with control of rectifier.

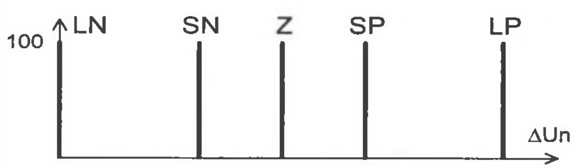

Fig. 4. Membership function of output
Rys. 4. Funkcja przynależności dla wyjścia regulatora rozmytego

4. MEASUREMENTS

Laboratory setup consists of the converter, RL load, the microprocessor control unit connected with PC computer. Two canals of D/A converter from control unit allow to present some inner variables which can visualize operation of PI or FL controllers (for examples delay angle α_z).

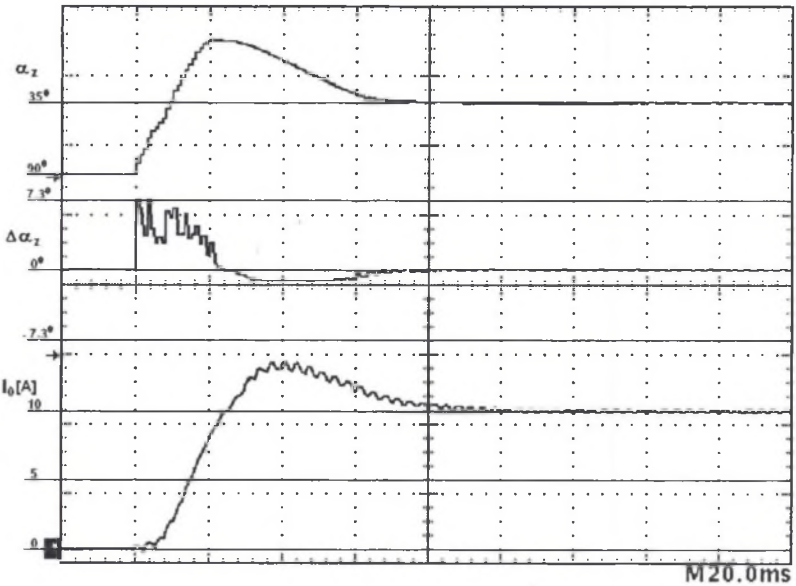

Fig. 5. Output current I_o, change of delay angle $\Delta\alpha_z$ delay angle α_z for FL controller, I_{ref}=10 A, RL load, τ_{RL}=12,2 ms

Rys. 5. Prąd prostownika I_o, kąt opóźnienia α_z dla regulatora rozmytego, I_{ref}=10 A, obciążenie RL, τ_{RL}=12,2 ms

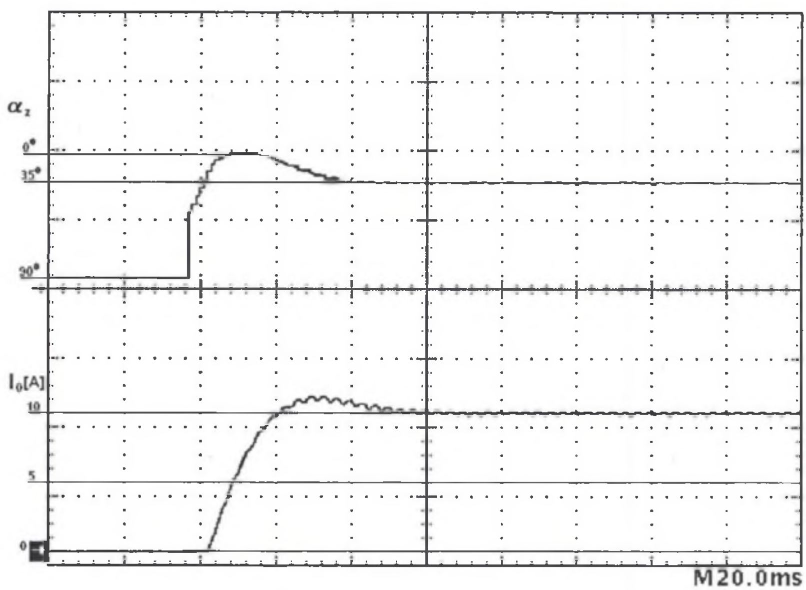

Fig. 6. Output current I_o, delay angle α_z for PI controller, I_{ref}=10 A, RL load, τ_{RL}=12,2 ms

Rys. 6. Prąd prostownika I_o, kąt opóźnienia α_z dla regulatora PI, I_{ref}=10 A, obciążenie RL, τ_{RL}=12,2 ms

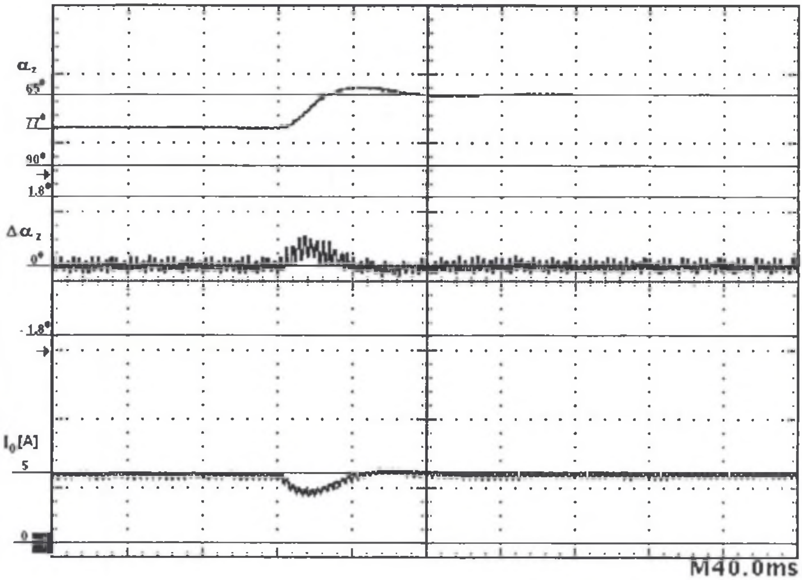

Fig. 7. Output current I_o, change of delay angle $\Delta\alpha_z$, delay angle α_z for FL controller, I_{ref}=5 A, RL load change R=10 Ω → 20 Ω, L=242 mH

Rys. 7. Prąd prostownika I_o, zmiana kąta opóźnienia $\Delta\alpha_z$, kąt opóźnienia α_z dla regulatora rozmytego, I_{ref}=5 A, zmiana obciążenia RL: R=10 Ω → 20 Ω, L=242 mH

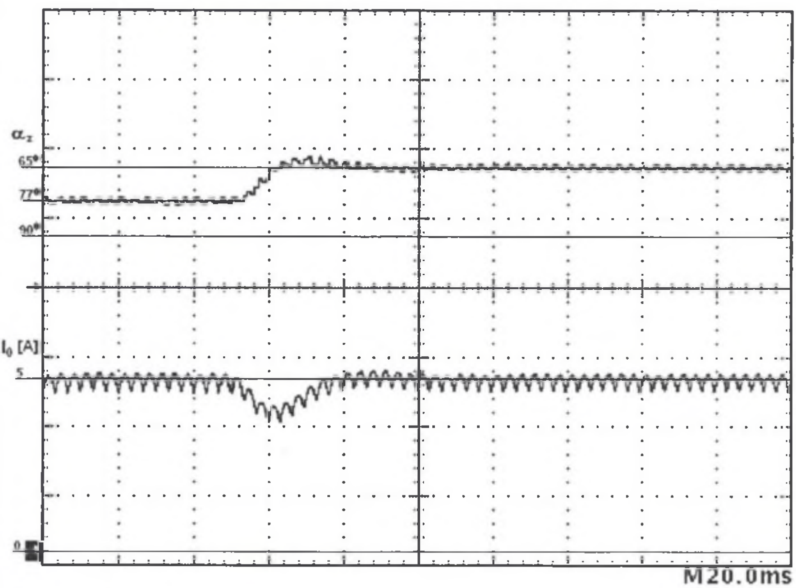

Fig. 8. Output current I_o, delay angle α_z for PI controller, I_{ref}=5 A, RL load change R=10 Ω → 20 Ω, L=242 mH

Rys. 8. Prąd prostownika I_o, zmiana kąta opóźnienia $\Delta\alpha_z$, kąt opóźnienia α_z dla regulatora PI, I_{ref}=5 A, zmiana obciążenia RL: R=10 Ω → 20 Ω, L=242 mH

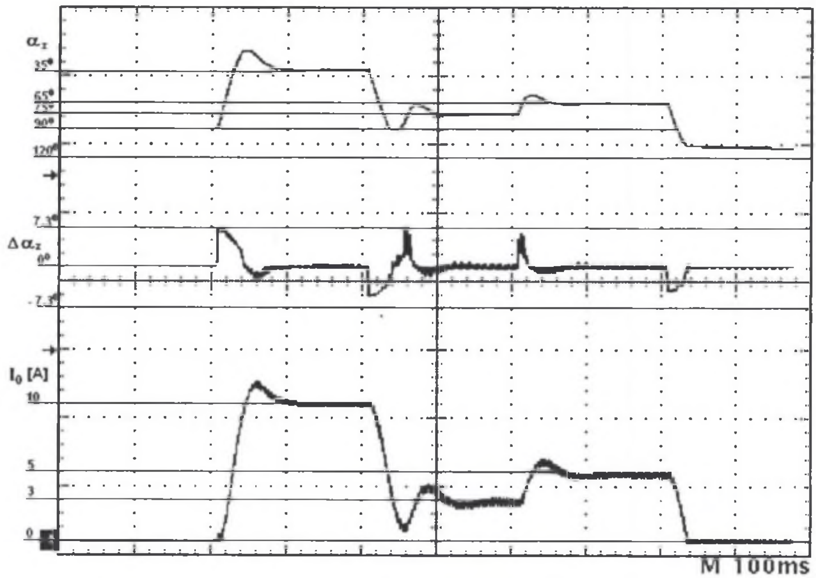

Fig. 9. Output current I_o, change of delay angle $\Delta\alpha_z$, delay angle α_z for FL controller, I_{ref}=10 A→5 A→3 A→5 A→0 A

Rys. 9. Prąd prostownika I_o, zmiana kąta opóźnienia $\Delta\alpha_z$, kąt opóźnienia α_z dla regulatora rozmytego, I_{ref}=10 A→5 A→3 A→5 A→0 A

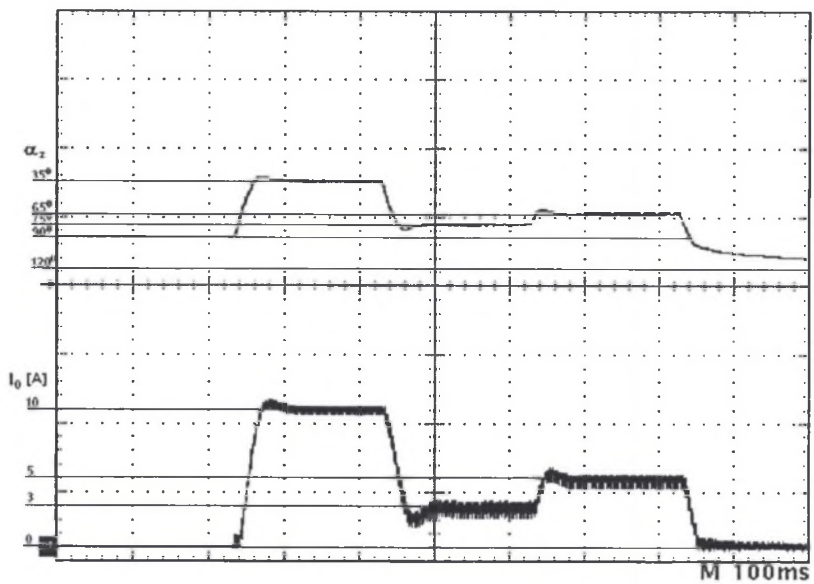

Fig. 10. Output current I_o, delay angle α_z for PI controller, I_{ref}=10 A→5 A→3 A→5 A→0 A

Rys. 10. Prąd prostownika I_o, kąt opóźnienia α_z dla regulatora PI, I_{ref}=10 A→5 A→3 A→5 A→0 A

First examples of measurements are presented in fig. 5 and 6. We can see response for current reference step (0 to 10 A) for both controllers. However the two responses are not identical, settling times are comparable. Unfortunately overshot for FL controller is bigger then for PI. Other measurements show that the responses of both controllers are dependent on parameters of RL load.

There are also obtain some measurements during transitions of load. In fig. 7 and 8 we can see measured output current during load change from 10 Ω to 20 Ω. Settling time is about 30 ms for PI controller and about 40 ms for FLC.

We made some other experiments with programming reference values of output current to check settling time and character of waveforms. Some of these waveforms for PI controler and FLC are presented in fig. 9 and 10.

5. CONCLUSIONS

It is possible to implement fuzzy logic controller algorithm using typical 16-bit microcontroller and processing time allows to control object with time constant till 5-10 ms.

The obtained results point out that PI controller can give better or similar results as classical FL algorithm for linear objects. The authors suppose that it is possible to obtain better results for FL controller by modification its structure and by increasing number of output fuzzy sets.

FL algorithm is much more difficult to implement in comparison to PI controller also time needed for all calculations is much longer.

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