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Modelling and Fuzzy Control of DC Drive

Bogumila Mrozek, Zbigniew Mrozek,
Cracow University of Technology, 24 Warszawska Str, PL 31-155 KRAKOW, Poland,
bmrozek@usk.pk.edu.pl, pemrozek@cyf-kr.edu.pl

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ABSTRACT

An industrial DC drive (22kW) with fuzzy controller is simulated. Two models (linear and nonlinear) and two controllers (PID and fuzzy) are investigated. Using fuzzy controller for DC drive operation was successful.

INTRODUCTION

Two mathematical models of a DC drive are used. The first model is build as linear transfer function of converter and DC motor. The second model is build using advanced blocks from *Power System Blockset* (PSB) library. The library is an extension of MATLAB/Simulink environment from The MathWorks Inc. Using fuzzy logic and PSB library model seems to be new and promising approach to control of an electric drive.

LINEAR MODEL OF DC DRIVE

A linear and nonlinear model of DC drive will be used. The linear model consists of two parts: converter/rectifier and DC motor. A linear model of DC motor (figure 1) was build using Simulink blocks. There are two inputs (voltage and load) and two outputs (angular motor velocity and current). Its parameters are computed automatically from nominal catalogue data: motor power, voltage, current, speed, etc). It is very convenient to use nominal motor data as rotor inductance and resistance. DC motor constant and other internal motor parameters are difficult to find.

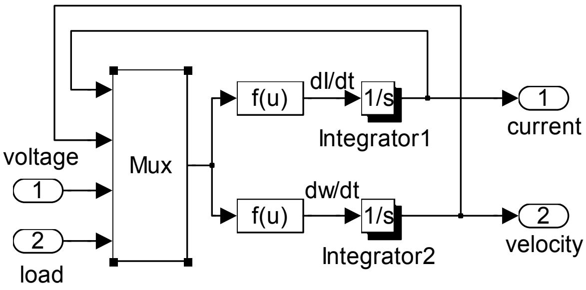

Fig. 1 Linear model of DC motor
(custom subsystem MotorDC)

Converter/rectifier is described as first order inertia

$$Gconv = \frac{kp(s)}{Tmip \cdot s + 1}$$

where:

kp -gain of converter/rectifier
Tmip -mean dead time of converter/rectifier

The dead time *Tmip* may vary from zero to one-half the period of an AC source (0.01s for 50 Hz) [Devan, 1984]. It is assumed that six-phase thyristor bridge with mean dead time *Tmip*=1.67ms is used in the converter.

A classic DC drive with two PID controllers is presented on figure 8. It was assumed to neglect a derivative signal and to use PI operation of a current controller only. Parameters of the current controller were derived from the model parameters using rules of module and symmetry. Then *Nonlinear Control Design Blockset (NCD)* was used for automatic tuning of the controller parameters (fig.2), to minimise the transient overshot.

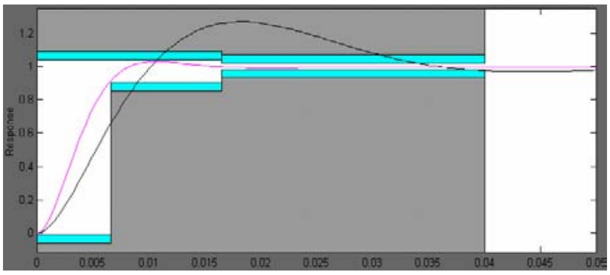

Fig. 2. Using *NCD Blockset* for tuning parameters of PI controller in the current loop

Simple transfer function model of motor current vs. voltage was used

$$Gmot = \frac{kia}{Ta \cdot s + 1}$$

where:

kia - gain of DC motor
Ta - armature circuit time constant

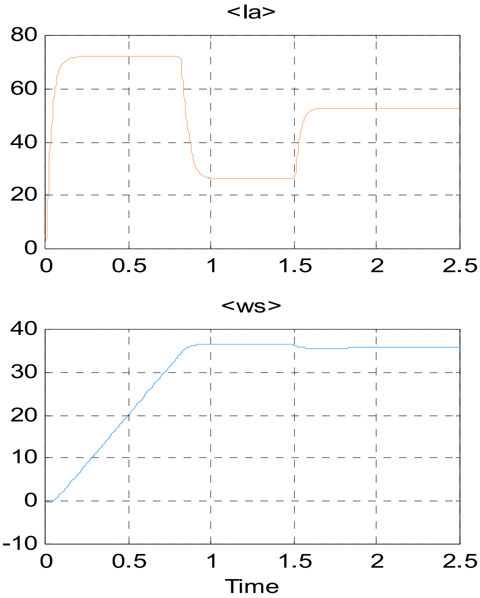

Fig. 3 Current (upper red) and angular velocity (lower blue) of DC motor. *Simulink* and linear model were used for simulation.

Similar procedure was used to find parameters of velocity controller. The simulation results (DC motor current and angular velocity vs. time) are presented on figure 3. This is raw simulation as linear model has very low granularity: AC component of current and switching of currents in thyristor bridge are neglected. Only envelope of transients can be seen on simulation output.

USING POWER SYSTEM BLOCKSET TO MODEL THE DC DRIVE

An advanced set of linear and nonlinear blocks can be found in *Power System Blockset*. Three AC sources, three-phase six-pulse converter, pulse generator and DC motor are taken from the library. They are used to prepare high quality model of three-phase DC drive (see figure 9).

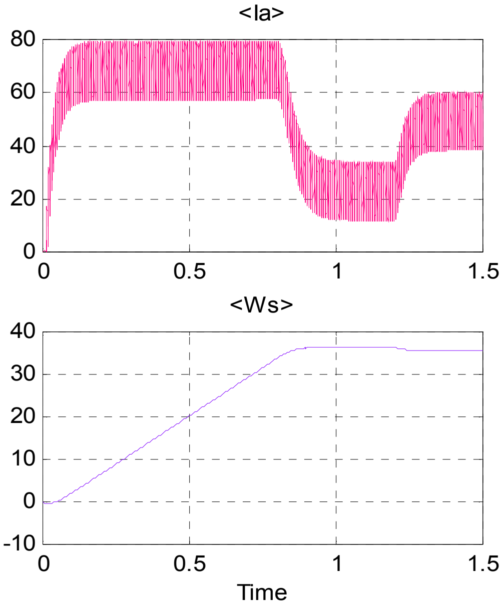

Fig. 4. Simulated current signal (red) and angular velocity (blue) using *Simulink* and *Power System Blockset* (see also fig. 5)

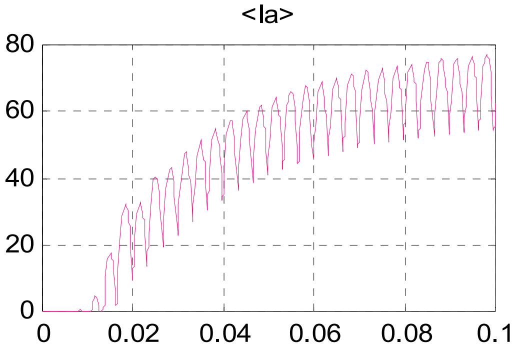

Fig. 5. Detail of simulated current signal using *Simulink* and *Power System Blockset*

The three-phase bridge converter is the most frequently used motor control system. Two of six thyristors conduct at any time instant. Gating of each thyristor initiates a pulse of load current; therefore this is a six-pulse controlled rectifier. The three-phase six-pulse rectifier is also capable of inverter operation in the fourth quadrant.

Electrical phenomena of thyristor bridge and DC motor are modelled very exactly. Simulation results (figure 4 and 5) are **almost exact** with real **measurement data on industrial object**, but computation is slow comparing to linear model.

FUZZY CONTROLLER OF DC DRIVE

The fuzzy controller is presented on figure 10. Advanced model using *Power System Blockset* is used, but transfer function model can also be useful for preliminary tuning of controller parameters.

Linguistic variables and rules

There are two fuzzy variables (error and INTEG error) and seven linguistic variables (from *big negative* to *big positive*). The fuzzy controller attributes are:

```
        type: 'mamdani'
        andMethod: 'prod'
        orMethod: 'max'
        defuzzMethod: 'centroid'
        impMethod: 'prod'
        aggMethod: 'max'
        input: [1x2 struct]
        output: [1x1 struct]
        rule: [1x25 struct]
```

The membership functions (`pimf` and `gausmf` are used) and rules are design tools that give opportunity to model a control surface and controller properties. It is obvious that using this attributes one can more precisely fulfil a quality criterion in full operational range. The control surface (figure 6) is defined with 25 rules.

RESULTS AND CONCLUSION

Simulation output for fuzzy controller is similar to PI controller output presented on figure 4 – unless one consider how controller react for external disturbation. The investigation showed that even simple fuzzy controller used to control DC drive operation (fig. 10) is more precise and faster than of PI controller (compare fig. 7 with fig. 5).

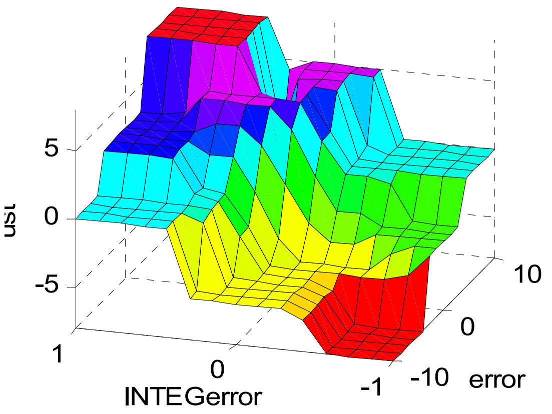

Fig. 6. Fuzzy control surface

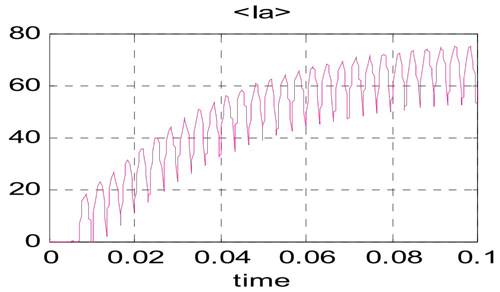

Fig. 7. Detail of simulation results (motor current). Fuzzy controller (here) react faster than PI (see fig. 5)

FINAL REMARKS

Both simple transfer function model and the advanced set of linear and nonlinear blocks from *Power System Blockset* are useful for tuning the DC drive control system. Advanced models build with *Power System Blockset* blocks are suitable for preliminary verification of control system, as AC component of current and switching phenomena of thyristor bridge are not neglected. The fuzzy controller is more difficult to design comparing with PID controller but has more design parameters and is more suitable to fulfil nonlinear quality criterion in all operational range – as seen on figure 6. For real time operation a discrete fuzzy algorithm can be implemented on microcomputer, DSP or ASIC chip, which is more suitable for industrial application.

ACKNOWLEDGEMENTS

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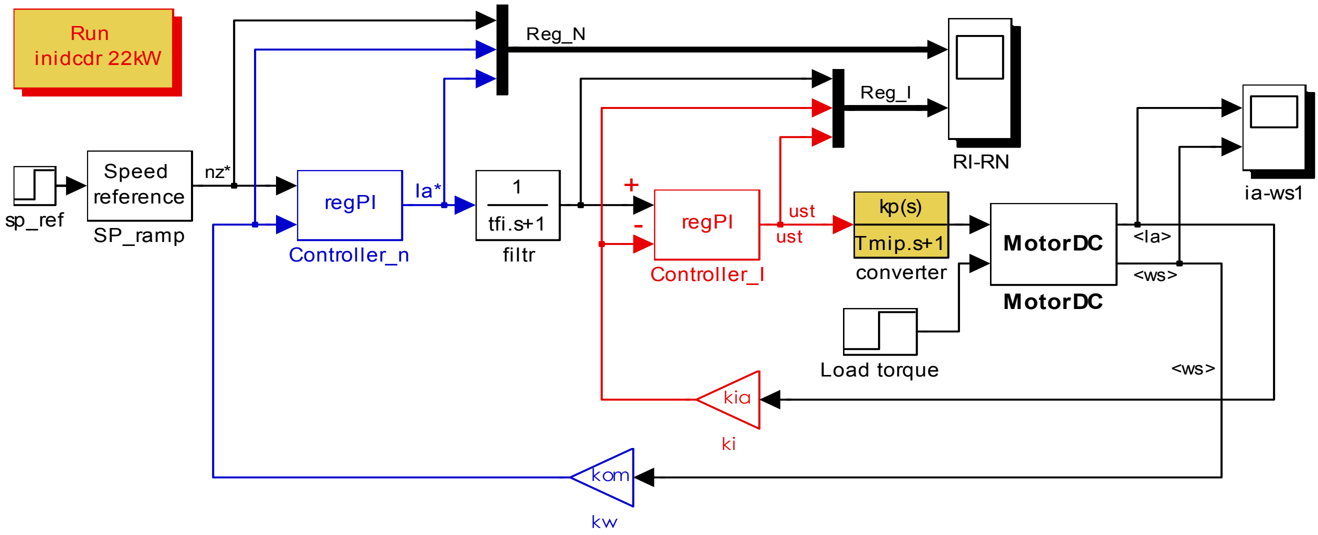

Fig. 8 DC drive with PI controllers in current and velocity loop.
Linear transfer function models are used

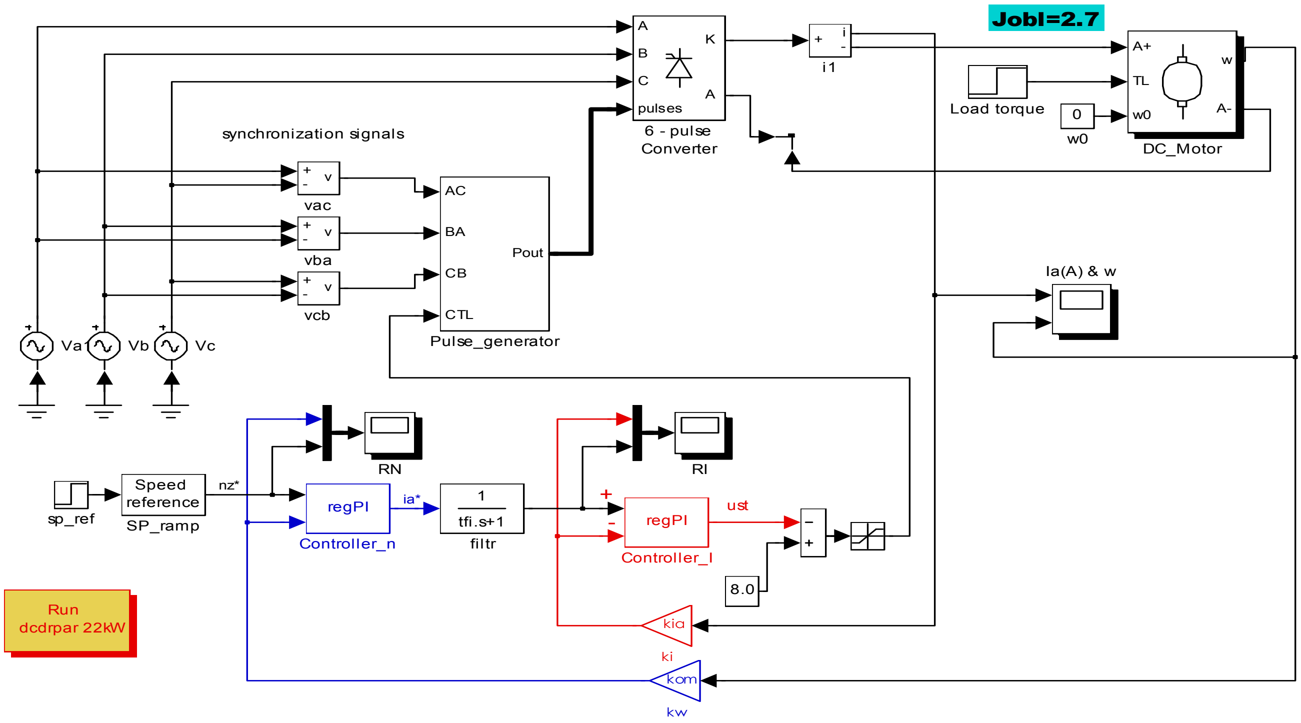

Fig. 9. DC drive with PI controllers in current and velocity loops.
Power System Blockset is used to build advanced drive model (upper part of block diagram)

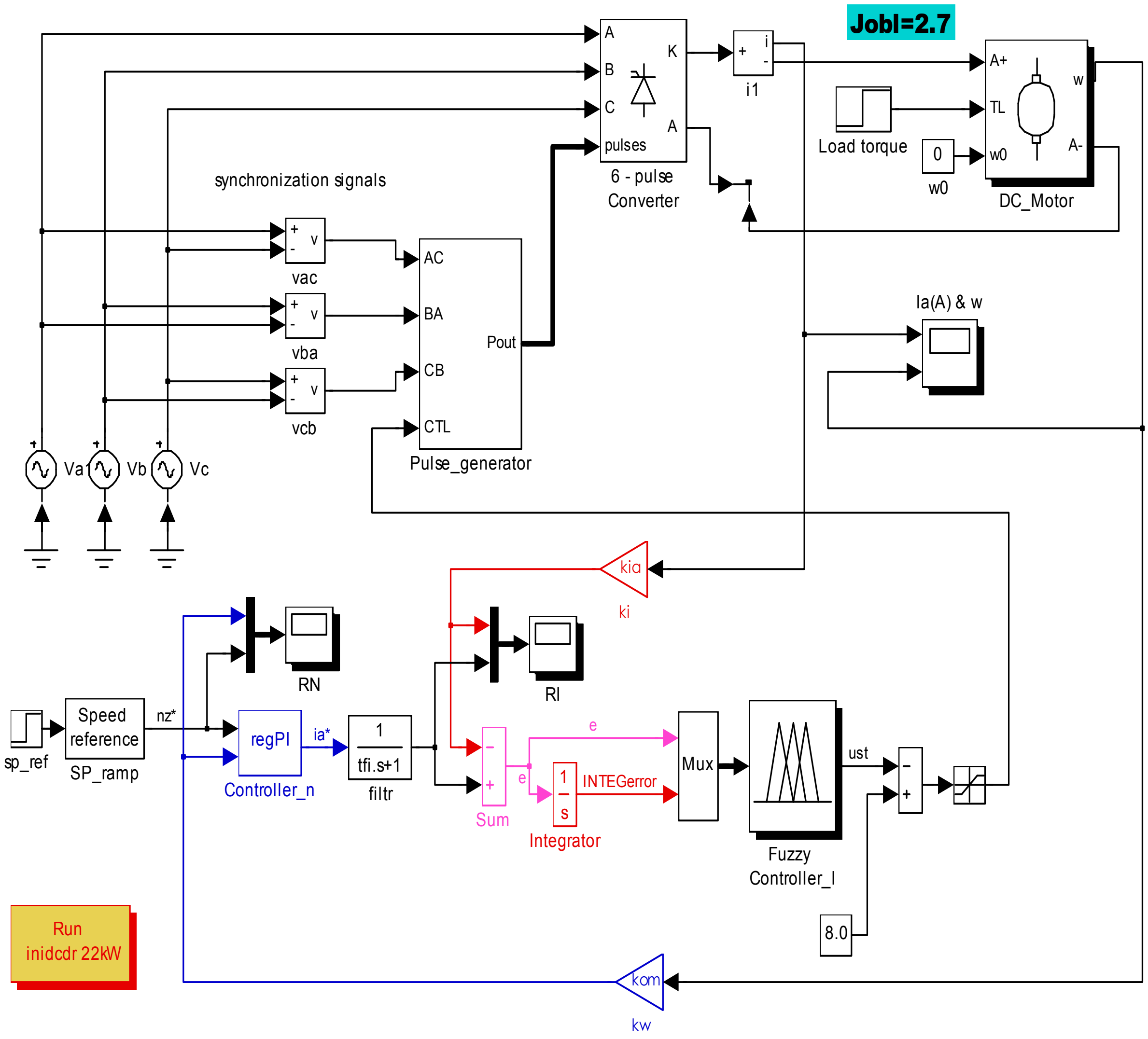

Fig.10. DC drive with fuzzy controller in current loop.
Power System Blockset is used to build advanced drive model (upper part of block diagram)

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