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ANALYSIS OF PARAMETRIC OPTIMIZATION OF FIELD-ORIENTED CONTROL OF 3-PHASE INDUCTION MOTOR WITH USING EVOLUTIONARY ALGORITHM

ANALÝZA OPTIMIMALIZACE PARAMETRŮ VEKTOROVÉHO ŘÍZENÍ TŘÍFÁZOVÉHO INDUKČNÍHO MOTORU POMOCÍ EVOLUČNÍHO ALGORITMU

Abstract

In this paper, the impact of regulators set and their types for the characteristic of rotational speed of induction motor was researched.. The evolutionary algorithm was used as optimization tool. Results were verified with using MATLAB/Simulink.

Abstract

V tomto příspěvku je popsán výzkum dopadu sady regulátorů a jejich typů na úhlovou rychlost indukčního motoru. Jako optimalizační nástroj byl použit evoluční algoritmus Výsledky byly ověřeny pomocí simulačního software MATLAB/Simulink.

Keywords

Evolutionary algorithm, induction motor, field-oriented-control.

1 INTRODUCTION

Modern control system of rotational speed of induction motor is vector control one. There are known many such control systems, ex.: field-orientated control, direct torque control [1, 4, 5]. In field-oriented control system the basic issue is selection of regulators' parameters [1, 4, 5, 7, 8]. This control system consists of four or five regulators: speed control, flux control, current controls and optionally torque control [1, 4]. In this paper, the impact of regulators set and their types for the characteristic of rotational speed of induction motor was researched. The evolutionary algorithm was used as optimization tool. Results were verified with using MATLAB/Simulink.

2 EVOLUTIONARY ALGORITHM

2.1 Basic definitions

The evolutionary algorithm is inspired by Darwin's Theory of Evolution and hence here are many lean words, ex.: individual, chromosome, gene, population, environment, etc. Evolutionary algorithm is the one, which looks for the best solutions among available ones. Single solution is called individual.

Individual

- represents a solution to the task with the evaluation function (quality index value),

- for one-dimensional case is marked according to the pattern (1) and shown on Fig. 1

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$$O_1 = [x_1, y_1, F(x_1, y_1)] \quad (1)$$

where:

x_1, y_1 – gene/chromosomes of Individual O_1,

$F(x_1, y_1)$ – value of fitness function of Individual O_1

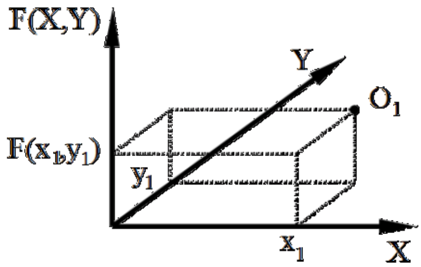

Fig. 1 Graphical presentation of Individual O_1

Task representation

Task representation is the way of record of chromosomes' values x_1, y_1 of Individual O_1 (1).

In this paper the possible solutions are the following ones [6]:

- representation of floating-point, where coordinates values of individuals are written as decimal numbers,

- fixed-oriented representation (ex. natural binary code, Gray's code), where coordinates values of individuals are written as binary sequences,

In case, which is described further representation of floating-point was used and chromosomes values from binary figure to floating-point one weren't calculated. Using the representation of floating-point in other way than in classic genetic algorithm calculate the result of work of evolutionary operators.

Population

The population is the set of individuals. In this paper algorithm with constant number of individuals was used. In this case we can listed [2, 3, 4, 6]:

- initial population – the set of generated and evaluated individuals in first step of algorithm work,

- the population – current set of individuals,

- new population – the set of individuals, which will be the current one in new generation.

Evolutionary operators

Evolutionary operators generate new individual or new individuals from individuals in the current population. There are two types of evolutionary operators:

– unary operators (for example mutation, progressive mutation),
– multi-ary operators (for example crossover).

Mutation

Mutation operator:

– selects individual randomly from the current population,
– the drawn individual is called a parent (P_1),
– on the basis of the individual and the Gaussian distribution, generates a new individual called descendent (S_2),

– has a limited range of activities (A) to approximately 30% -50% of full scale of the variable (Fig. 2)

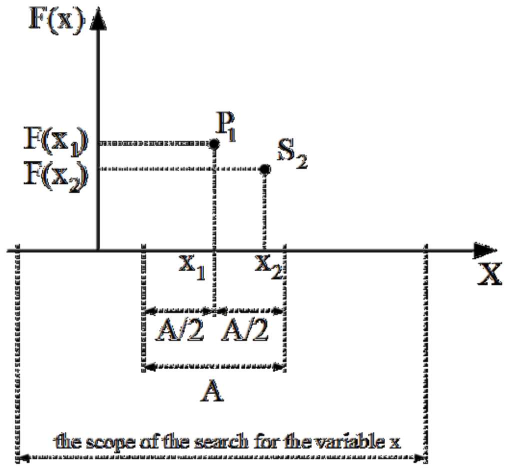

Fig. 2 Graphical presentation of work of mutation operator on Individual P_1

Progressive mutation:

Progressive mutation operator:

– selects individual randomly from the current population,
– the drawn individual is called a parent (P_1),
– on the basis of the individual and the Gaussian distribution, generates a new individual called descendent (S_3),
– has a limited range of activities (B) to approximately max 1% of full scale of the variable, Fig. 3.

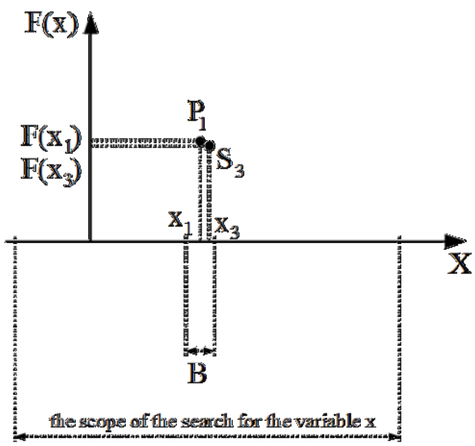

Fig. 3 Graphical presentation of work of progressive mutation operator on Individual P_1

Crossover

Crossover operator:

– randomly selects two individuals from the current population (P_1, P_2),
– on the basis of individuals P_1, P_2 generates offspring individual S,
– individual child (S) is always located between individuals parents (P_1, P_2), Fig. 4.

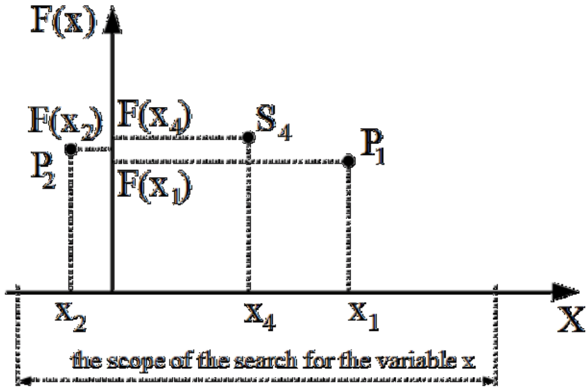

Fig. 4 Graphical presentation of work of crossover operator with Individuals P_1, P_2

Selection

The operator is responsible for choosing the selection of individuals from the current population to the new population. Choice is made at random.

Operator selection [2, 3, 4, 6]:

- selected individuals, based on their fitness function,
- to maximize the quality index for a better individual is an individual with a higher value of the fitness function,
- maintains a constant population size,
- there are known several types of operator selection:
  - roulette method,
  - method tournament,
  - deterministic method.

Roulette method:

- a value of the fitness function (F(x)) is assigned to each individual,
- based on the value assigned to an individual slice,
- the larger is the value of the fitness function, the larger the slice is assigned,
- Individuals are selected to the new population by "turning wheel", Fig. 5.

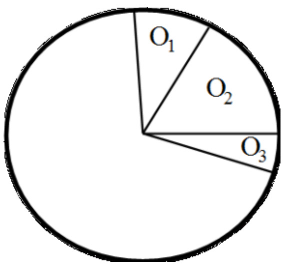

Fig. 5 Graphical presentation of roulette method for $F_{O2}(x_2)>F_{O1}(x_1)>F_{O3}(x_3)$

Method tournament:

- a value of the fitness function (F(x)) is assigned to each individual
- two individuals are selected randomly from the current population,
- these chosen individuals values of the fitness function are compared with each other,
- Individuals with the better value of the fitness function are chosen to the new population.

Deterministic method:

– a value of the fitness function (F(x)) is assigned to each individual
– the worst individuals are rejected,
– only individuals with the best value of the fitness function are selected to the new population.

Flow chart of evolutionary algorithm

Flow chart of evolutionary algorithm is shown on Fig. 6.

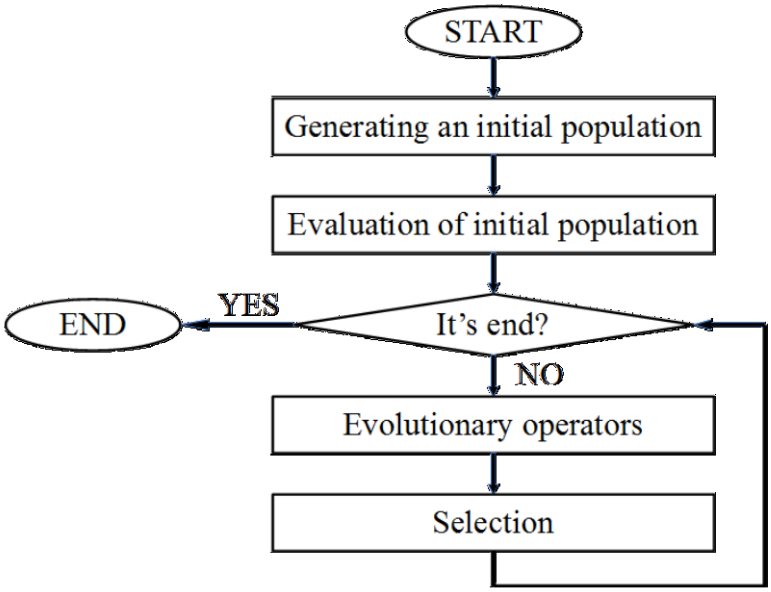

Fig. 6 Flow chart of evolutionary algorithm

After start of running algorithm the initial population is generated. In next step of program the value of fitness function is assigned to each individual. The condition of the end of program is checked. In this paper the constant number of generations was used (program loops). The evolutionary process is started at that moment. Evolutionary operators create new individuals based on current population. New individuals are evaluated (value of fitness function is assigned to them) and added to current population. At that moment the current population is increased by individuals generated by evolutionary operators. Selection operator is responsible for keeping the constant number of individuals and the evolution process. The condition of the end of program is checked again and the process starts from the beginning.

3 EXAMINED CONTROL SYSTEM

The field-oriented system with induction motor was researched. Very popular simplifications were used. Then the system has the following qualities [1, 4]:

– consists of controlling the stator currents represented by a vector,
– this control is based on projections which transform a three-phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system,
– these projections lead to a structure similar to that of a DC machine control,
– field orientated controlled machines need two constants as input references: the torque component (aligned with the q co-ordinate) and the flux component (aligned with d co-ordinate),
– was tested by simulation using MATLAB/Simulink,
– induction motor was used as the control object,

– mathematical model of the induction motor is lead out from the classical equations with the regard of universal, practical simplifications.

Flow chart of control system is shown on Fig. 7.

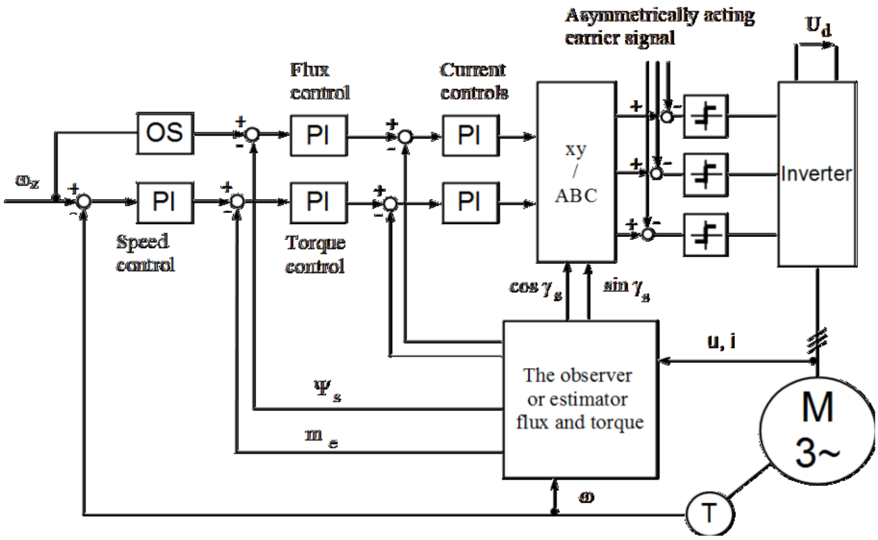

Fig. 7 Flow chart of field-oriented system with 3-phasies motor, where:

m_e – electromagnetic torque,

ω – speed,

ω_z – set speed,

Ψs –flux,

u – 3-phase voltage in the coordinate system of natural ABC,

i – 3-phase current in the coordinate system of natural ABC,

γ_s – angle needed to transform between coordinate systems orthogonal axes of the rotor 0dq and the natural coordinate system ABC.

Many variants of this control system were examined. In all cases the evolutionary algorithm calculates regulators parameters. Reference signals were: step change of rotational speed (2) and step change of load torque (3).

$$n = \begin{cases} 0\ [rpm]\ for\ t < 1\ [s] \\ 600\ [rpm]\ for\ t \geq 1\ [s] \end{cases} \quad (2)$$

$$M_{obc} = \begin{cases} 0\ [Nm]\ for\ \ t < 3\ [s] \\ 10\ [Nm]\ for\ t \geq 3\ [s] \end{cases} \quad (3)$$

Tested control systems differ in regulators numbers and regulators types. Below there are juxtaposed all tested control systems with vector record of individuals, which are assigned to them:

– basic control with five controls PI (speed control, flux control, torque control, current controls) – Fig. 8; the individual has 10 coordinates - $O_{5PI} = [K_s, K_f, K_t, K_{c1}, K_{c2}, T_s, T_f, T_t, T_{c1}, T_{c2}]$,

where:

K_s – speed controller gain,

K_f – flux controller gain,

K_t – torque controller gain,

K_{c1}, K_{c2} – current controllers gain,

T_s – factor depending on the integral time of speed controller,

T_f – factor depending on the integral time of flux controller,

T_t – factor depending on the integral time of torque controller,
T_{c1}, T_{c2} – factors depending on the integral time of current controllers.

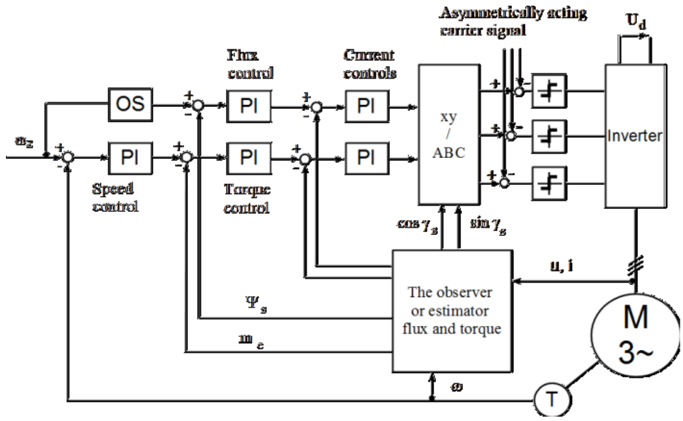

Fig. 8 Basic control with five controls PI

– control with five controls P (speed control, flux control, torque control, current controls) – Fig. 9; the individual has 5 coordinates - $O_{5P} = [K_s, K_f, K_t, K_{c1}, K_{c2}]$,

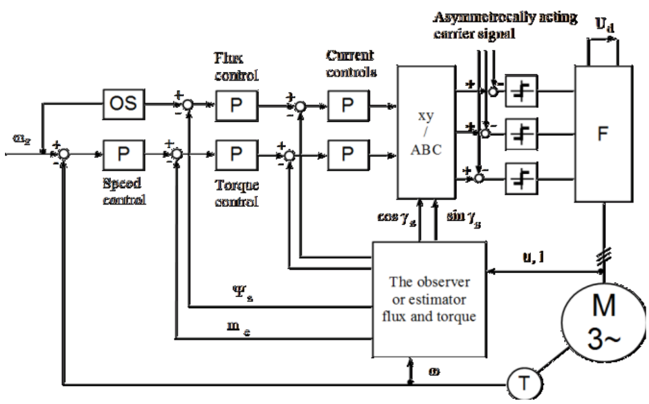

Fig. 9 Control system with five controls P

– control with four controls PI (speed control, flux control, current controls) without torque controller – Fig. 10; the individual has 8 coordinates; $O_{4PI} = [K_s, K_f, K_{c1}, K_{c2}, T_s, T_f, T_{c1}, T_{c2}]$,

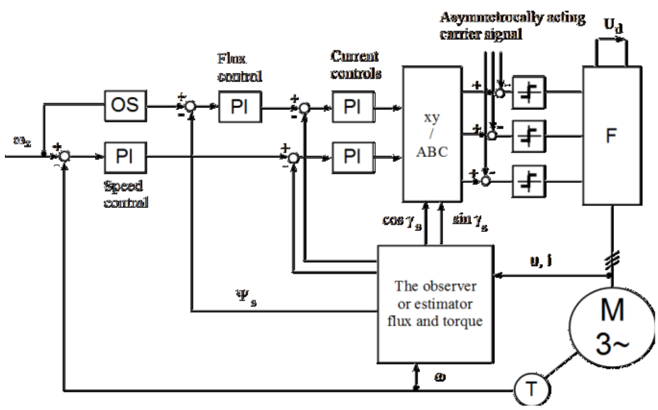

Fig. 10 Control system with four controls PI

– control with four controls P (speed control, flux control, current controls) without torque controller – Fig. 11; The individual has 4 coordinates; $O_{4P} = [K_s, K_f, K_{c1}, K_{c2}]$,

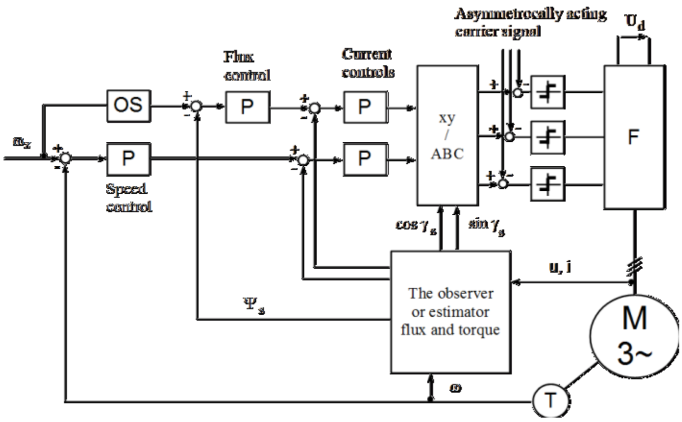

Fig. 11 Control system with four controls P

All results of parameter optimization were calculated by evolutionary algorithm. Quality of index was calculated as the sum of squares of errors in discrete moments of time between measured values of registered during starting rotational speed and values, which were calculated on the basis of individual. Function reference was step function (step change in speed and step change in load torque). The parameters of an evolutionary algorithm were also a subject to research. The impact of different selection operators (roulette method, method tournament, deterministic method) on the results of the evolution was examined. A combinations of the selection methods were also tested. The impact of evolutionary operators (mutation, progressive mutation, crossover) on the received results. Evolutionary algorithm has parameters as are shown in table 1.

Tab 1. Evolutionary algorithm parameters

Number of generations	100 000
Population size	200
Number of crossover to generation	80
Number of mutation to generation	80
Number of progressive mutation to Generation (number of variable)	ascending from 30 to 100
Width of the range of mutation	40% of range
Width of the range of progressive mutation	1% of range

The best of the all individuals calculated with using evolutionary methods (with the lowest value of the evaluation function) was the individual for the control system with 5 PI controllers with values from table 2.

Tab. 2. Parameters with fitness function of the best individual

K_{c1}	K_{c2}	K_f	K_t	K_s	T_{c1}	T_{c2}	T_f	T_t	T_s	F [rpm]
12.9	15.0	12.1	0.21	1.91	2.99	2.00	3.96	0.52	9.02	$1.71 \cdot 10^4$

The characteristic of the rotational speed for the best individual is shown in Fig. 12.

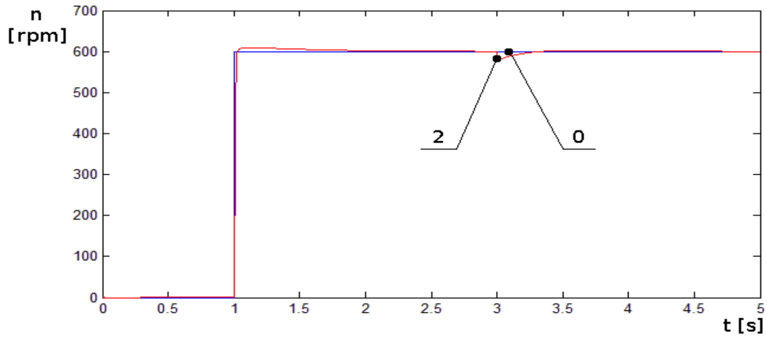

Fig. 12 Characteristic of the rotational speed for the best individual

4 CONCLUSIONS

The evolutionary algorithm to parametric optimize of field-oriented control system with induction motor was examined. The best control system among the analyzed was selected. The impact of some parameters on the results of an evolutionary algorithm was researched. Obtained set regulators measure up the initial assumptions. Unfortunately, the settings are not optimal due to the nature of the evolutionary algorithm. The obtained results are suitable as input to other optimization methods.

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