Parameters Identification of Controlled Systems with Electrical Drives Using Genetic Algorithms

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Abstract— The electrical controlled drives are described as controlled systems that contain one or two large time constants and several small time constants, whose influence is replaced by approximately sum time constant. The large time constants are then compensated by a serial correction using a controller, while the sum time constant remains uncompensated. The quality of the control is assessed according to the response of the control loop to step change of the input variable. In the paper, there is used a genetic algorithm to identify the unknown time constants of the controlled system with the electrical drive from the step response characteristic.

1. INTRODUCTION

There are a lot of new approaches and principles which are based on a relatively new scientific discipline which is called soft computing. The main feature of soft computing is a departure from traditional modeling based on Boolean logic, analytical models, sharp classification and deterministic search. Among the main representative of soft computing we can include fuzzy logic, neural networks and genetic algorithms. Genetic algorithms solve optimization problems in different fields of the industry. In the field of electrical drives, the genetic algorithms can be used to identify the parameters of the controlled system, optimization of the controller parameters settings and optimization of the parameters adjustment of adaptive controllers [1–4].

2. CONTROLLED SYSTEMS WITH ELECTRICAL DRIVES

Different methods of analysis and synthesis are used to design of electric controlled drives which have to fulfill given static and dynamic requirements. The quality of the control is assessed according to the response of the control loop to step change of input variable (see Fig. 1). From a practical point of view, four factors are most important for the assessment of control quality: rise time t_r, settling time t_s, overshoot y_m and steady state error.

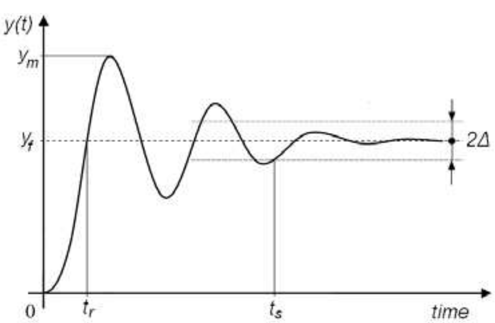

Figure 1: Typical step response for an under damped second order system.

The main requirements are a good dynamics of the control which is given by short rising time t_r and small overshoot y_m. These two parameters are contradictory and it is not possible to fulfill both of them at the same time. Appropriate settings of t_r and y_m determine the right curve shape of an open loop step response in time domain. In real control loop, there are some errors that it is not possible to compensate. These errors, for example voltage ripple, measurement errors and controller errors, determine the practical achievable static accuracy.

For the electrical controlled drives, a cascade structure is often used. The cascade control structure consists of several superior and subordinate control loops [5–8].

The serial correction method is mostly used to get right static and dynamic parameters of the control loop. For illustration, there will be considered the following transfer function of the controlled system in Laplace domain:

$$F_S(s) = \frac{K_S}{(1+sT_1)(1+sT_2)\dots(1+sT_n)} \tag{1}$$

The controlled systems with the electrical drives are described by the transfer function that contains one or two large time constants and several small time constants. The open control loop is described by transfer function:

$$F_{OL}(s) = F_C(s) \cdot F_S(s) = F_C(s) \cdot K_S \frac{1}{(1 + sT_S)} \frac{1}{(1 + sT_\Sigma)} \tag{2}$$

where $F_S(s)$ — transfer function of the controlled system; $F_C(s)$ — transfer function of the controller; K_S — gain of the controlled system; T_S — large time constant of the controlled system; T_Σ — uncompensated sum time constant.

For the control of the output quantity, it can be used the PI controller with the parameters K_{Ci} and T_{Ci}:

$$F_C(s) = K_{Ci} \frac{(1 + sT_{Ci})}{sT_{Ci}} \tag{3}$$

3. GENETIC ALGORITHM APPLICATION FOR PARAMETER ESTIMATION

The most important part of the genetic algorithm is the fitness function — an equation describing searched problem. The first population is generated randomly from specified range of values. According to the results of the individual in the fitness function for each individual is assigned a fitness value that reflects how strong this individual is. The strongest individuals continue in the algorithm and the weaker die [9].

Next is applied operations of mutation and crossover of most powerful individuals. During the crossing parents remain and the population grows by the new offspring resulting from accidental crossing of chromosomes randomly selected individuals — parents. The newly formed individual may be stronger than parents or weaker and dies in the next generation. The next step is the implementation of a mutation. This creates new individuals by mutation of individuals randomly selected from the population. In the developed algorithm is mutation implemented by multiplication chromosomes and random value close to one. In the next step of the algorithm are randomly generated new individuals. If not to create new random individuals, the space would be poorly scanned and the algorithm would get stuck in a local extreme of fitness function. Add new randomly generated individuals ensures a random search of the entire area, allowing the algorithm to jump out of the field of local extreme. The population was thus extended by new individuals resulting from the crossing and mutation of new individuals, but also randomly generated individuals. The whole population progresses to the next generation, where the process is repeated again — determining of fitness values-selection-crossover-mutation — the emergence of new randomly generated individuals. This process is repeated continuously till not reached the desired number of generations or until the individual is sufficiently mature — high enough fitness value [9].

The measured points and the function which describe the controlled system are loaded to the developed application. Chromosomes of the individual are function parameters and function values are calculated in measured points. Differences between measured and calculated values are calculated and summed. Total sum of the deviations then indicates how the individual is strong. The lower sum of differences means that the individual is stronger. The aim therefore is to find the parameters of the function to function as close as possible to the measurement points.

Summation of differences has the consequence that in this case the behavior of the function exactly intersects some points and some points are disproportionately away. Sum of differences is the lowest in this case. Even during the fitting function all points can provide the sum of squared differences. The sum of squared deviations is smaller number than the large square of one difference.

The sum of the differences is exactly interleaves the most points and ignores points outside the course of function. The sum of the deviations quadrates create graphs of functions uniformly interleaved all points.

All measurements generally are flawed and because of this error sometimes it is not possible to achieve sufficient results by substituting into the equation or by inserting of the measured points in to the system of equations and solve the equation parameters. In case of an inaccurate measurement should be measured points evenly interspersed by curve.

4. SIMULATION RESULTS

For the simulation, there was used the current loop of the vector controlled induction motor (IM) supplied by the frequency converter which consists of the input rectifier, DC voltage link and voltage source inverter (VSI). Basic parameters of the IM are: rated power 2.2 kW, rated speed 1420 rpm, rated voltage 230 V/400 V, rated current 8.4 A/4.7 A, rated torque 14.8 Nm, stator resistance 3.71 Ω, stator inductance 330 mH, leakage coefficient 0.0953, moment of inertia 0.005 kgm^2.

The resulting transfer function of the current loop that includes the voltage source inverter and its control part, current sensor and AD converter (ADC) is given:

$$F_{SI}(s) = \frac{K_M K_I K_{AD}}{R_S} \frac{1}{(1+sT_I)} \frac{1}{(1+sT_\Sigma)} = K_{SI} \frac{1}{(1+sT_I)} \frac{1}{(1+sT_\Sigma)}$$
$$= 650.54 \frac{1}{(1+s\cdot 0.00847)} \frac{1}{(1+s\cdot 0.000125)} \quad (4)$$

where K_{SI} — total gain of the current loop; K_M — voltage gain of the VSI, K_I — gain of the current sensor, K_{AD} — gain of the ADC, R_S — stator resistance, T_I — large time constant, T_{NKI} — small sum time constant.

The voltage gain of the VSI with the comparative PWM is defined as follows: $K_M = U_{\text{DC-link}}/U_{\text{Cmax}} = 650.54$, where $U_{\text{DC-link}}$ — DC-link voltage calculated for the rated stator voltage of the IM; U_{Cmax} — maximal control voltage with the value 1 which is given in the control software. The gain of the current sensor and ADC is defined in the control software: $K_I K_{AD} = 1$.

The large time constant T_I is calculated using IM parameters: $T_I = \sigma L_S/R_S = 0.0954 \cdot 0.33/3.71 = 8.47\,\text{ms}$. Small sum time constant T_Σ is defined as follows: $T_\Sigma = 1.5 \cdot T_{SI} + T_{VSI} =$

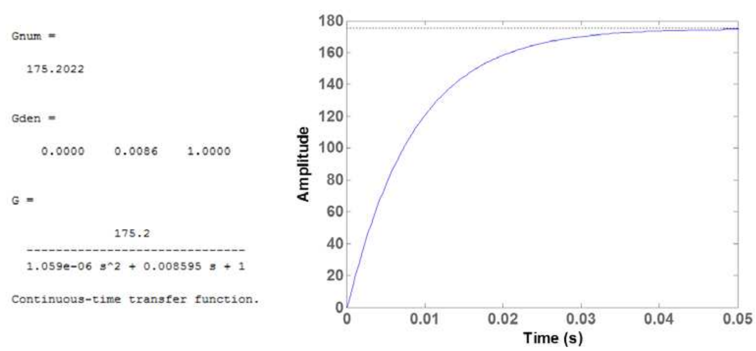

Figure 2: Step response of the open current control loop.

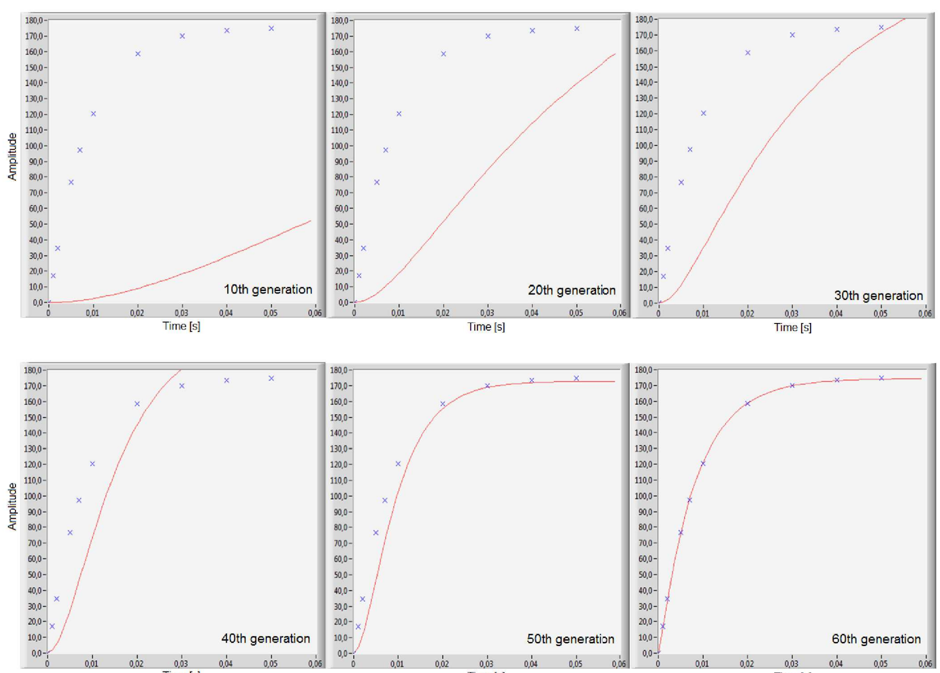

Figure 3: Development of the fittest individuals in each generation.

$1.5 \cdot 50 \cdot 10^{-6} + 50 \cdot 10^{-6} = 0.125\,\text{ms}$, where T_{SI} — sampling period of the current control loop; T_{VSI} — time delay of the VSI ($T_{VSI} = 1/2f_s$; switching frequency $f_s = 10\,\text{kHz}$).

Step response in time domain (see Fig. 2) is described by the following equation:

$$y = K\left\{1 - \left[\left(\frac{T_1}{T_1 - T_2}\right)e^{-\frac{t}{T_1}} - \left(\frac{T_2}{T_1 - T_2}\right)e^{-\frac{t}{T_2}}\right]\right\} \tag{5}$$

The step response of the described current control loop was obtained using Matlab code.

A few random points from step response were taken and applied into developed LabVIEW application based on the genetic algorithm. The equation of the step response in time domain is basically searched fitness function implemented into application. The genetic algorithm is used to find parameters $K = K_{SI}$, $T_1 = T_I$, and $T_2 = T_\Sigma$ of the step response in time domain. The population of 50 individuals and 60 generation were chosen.

Figure 3 shows the improvement of the function graph with the best individual in each generation. In each generation the sum of the deviations is much smaller and the curve follows the given points. The obtained parameters of the controlled current loop using the described genetic algorithms are: $K = K_{SI} = 175.2035$, $T_1 = T_I = 0.00847085\,\text{s}$, $T_2 = T_\Sigma = 0.00012495\,\text{s}$.

5. CONCLUSIONS

The designed GA application is able to find the important parameters of the controlled systems with the electrical drives. The achieved error is less than 0.1% in the sixtieth generation with the first population size of fifty individuals. This application can be used for almost every estimation tasks, if the controlled system is defined by the measured step response. The fitness function has to be chosen correctly.

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