Parameters Identification of Separately Excited DC Motor using Adaptive Tabu Search Technique

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Abstract

This paper presents the parameters identification for a DC motor using adaptive tabu search technique. The speed responses from a testing are used in the ATS searching process. The results show that the ATS technique is very useful and easily applied for a system identification application.

1. Introduction

DC motors are widely used in industries. The advantages of DC motor are as follows: it can be controlled for a wide range, can be easily used for a constant torque and speed, can be quickly accelerated or decelerated, and can response to a feedback control [1]. Hence, DC motors are the important machine in the most control systems such as electrical systems in homes, vehicles, trains, and aircrafts. It is well known that the mathematical model is very crucial for a control system design. For a DC motor, there are many models to represent the machine behavior with a good accuracy. However, the parameters of the model are also important because the mathematical model cannot provide a correct behavior without correct parameters in the model. Normally, the parameters can be determined by the testing. These parameters from testing sometime are incorrect or not good enough for the design because the testing process is very complicated. As a result, the mathematical models provide some errors. Therefore, there are many techniques to determine machine parameters to achieve the better accuracy. The reported techniques for searching parameters are Tabu search [2], Kalman filter [3], genetic algorithm [4]-[5], artificial neural networks [6], and etc.

This paper presents the application of adaptive Tabu search (ATS) to determine the DC motor parameters. The ATS technique is widely used for the optimization problem because it can escape the local optimum point to the global point. The overview of DC motor model is described in Section 2. The testing results of DC motor for the identification process are given in Section 3. The concept of ATS for machine identification is explained in Section 4 and the results of searching machine parameters via the ATS technique are shown in Section 5. Finally, the conclusion and discussion are addressed in Section 6.

2. The mathematical model of DC motors

2.1. The equivalent circuit

The equivalent circuit of separately excited DC motor [7] consists of independent two circuits, armature circuit and field circuit, in which loads are connected to the armature circuit as shown in Fig. 1.
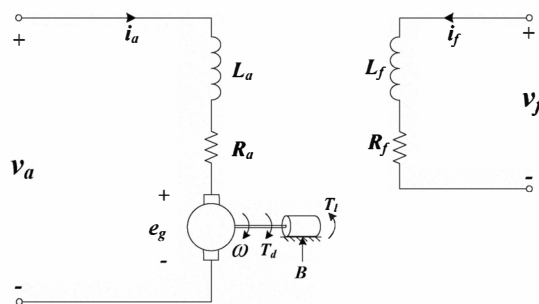

Figure 1. The equivalent circuit of separately excited DC motor

2.2. The mathematical model

From Figure 1, Kirchoff's voltage law (KVL) is applied to the armature circuit. These can be written.

$$v_a = i_a R_a + L_a \frac{di_a}{dt} + e_g \qquad (1)$$

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Setting e_g in (1) equal to $K_v i_f \omega$, the armature voltage equation in (1) becomes

$$v_a = i_a R_a + L_a \frac{di_a}{dt} + K_v i_f \omega \qquad (2)$$

where K_v is a voltage constant (V.s/rad).
Taking the Laplace transform into (2) yields

$$V_a(s) = I_a(s)R_a + L_a s I_a(s) + K_v I_f \omega(s) \quad (3)$$

The equation (3) can be rewritten to a new form to give

$$I_a(s) = \frac{V_a(s) - K_v I_f \omega(s)}{sL_a + R_a} \qquad (4)$$

From Fig.1, the mechanical motion equation is given by

$$T_d = J \frac{d\omega}{dt} + B\omega + T_L \qquad (5)$$

Taking the Laplace transform into (5) and setting $T_d(s) = K_t I_f I_a(s)$ and $T_L(s)=0$ yields

$$\omega(s) = \frac{K_t I_f I_a(s)}{sJ + B} \qquad (6)$$

where K_t is a torque constant (N.m/A).
Substituting $I_a(s)$ from (4) into (6), the transfer function between armature voltage (V_a) and motor speed (ω) can be written

$$\frac{\omega(s)}{V_a(s)} = \frac{K_t I_f / R_a R_f B}{\left(\dfrac{L_a J}{R_a B}\right)s^2 + \left(\dfrac{L_a}{R_a} + \dfrac{J}{B}\right)s + \left[1 + \dfrac{\left(K_v V_f\right)^2}{R_a R_f^2 B}\right]} \qquad (7)$$

Setting $K_v = K_t$ [8] to give

$$\frac{\omega(s)}{V_a(s)} = \frac{K I_f / R_a R_f B}{\left(\dfrac{L_a J}{R_a B}\right)s^2 + \left(\dfrac{L_a}{R_a} + \dfrac{J}{B}\right)s + \left[1 + \dfrac{\left(K V_f\right)^2}{R_a R_f^2 B}\right]} \qquad (8)$$

where $K = K_v = K_t$

2.3. DC motor parameters for ATS searching

There are six parameters of a DC motor as shown in (8) for ATS searching. These parameters are as follows

- R_a is an armature resistance (Ω)
- R_f is a field resistance (Ω)
- L_a is an armature inductance (H)
- J is a moment of inertia (kg.m^2)
- B is a viscous friction coefficient (N.m.s/rad)
- K is a constant value

From the above parameters, R_a and R_f can be determined from the measurement. For the DC motor of this paper, R_a and R_f are equal to 13 Ω and 591Ω, respectively. Note that these values are set as an initial solution for the ATS method. For the four remaining parameters, their initial values are randomly determined. This is because the practical measurement for these parameters is very complicated.

3. DC Motor testing

The rated DC motor for this paper is as follows:

Armature circuit: $V_{a,rated} = 220$ V, $I_{a,rated} = 2.2$ A, $P_{rated} = 0.37$ kW, $\omega_{rated} = 2360$ rpm
Field circuit: $V_{f,rated} = 220$ V, $I_{f,rated} = 0.3$ A

The results from DC motor testing will be used for ATS searching. For testing, the armature voltages of 60, 100, 160, 200, and 220 V were imposed with a constant field voltage (equal to rated voltage 220 V) under a no-load condition. The experimental rig of the testing is shown in Figure 2. The speeds of DC motor for each armature voltage are depicted in Figure 4.
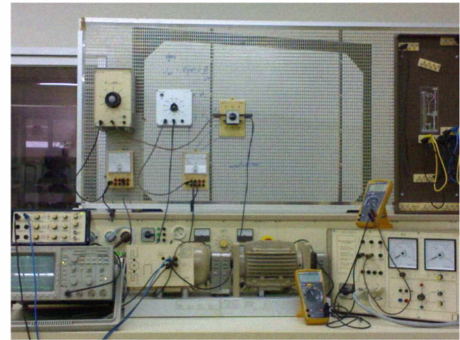

Figure 2. The experimental rig for DC motor testing

4. Applying ATS algorithm to a DC motor identification

ATS technique is the extended version of the Tabu search (TS) algorithm by adding the both concepts, namely back tracking and adaptive radius. These both concepts can improve the performance of TS method. The TS technique normally provides the local solution when the problem is complicated having many local points. Hence, the back tracking part and adaptive radius added to TS algorithm (called ATS) can escape the local lock to provide the global solution. The more details of ATS can be found in [9]. The diagram of ATS for determining the DC motor parameters is depicted in Figure 3.
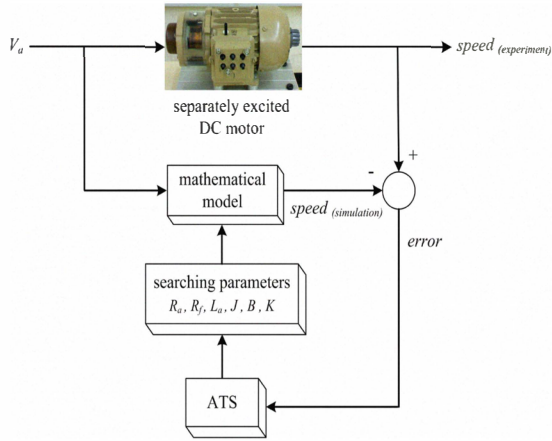

Figure 3. Block diagram for searching DC motor parameters using ATS

In Figure 3, the ATS method will search the DC motor parameters (6 parameters) and then use these parameters with equation (8) to calculate the speed of each armature voltage. The speed calculated from (8) with parameters from ATS is called $Speed_{(simulation)}$ as shown in Figure 3. The machine parameters in (8) are varied following on the ATS algorithm until a matched speed response between $Speed_{(simulation)}$ and $Speed_{(experiment)}$ is obtained. The experimental results of machine speed are given by the testing from Section 3 as shown in Figure 4. In terms of an optimization problem, the ATS will search the appropriate parameters of the motor to minimize the error value between the simulation and the testing. This error can be calculated by using the root mean square (rms) definition as given by

$$e_k = \sqrt{\frac{\sum_{i=1}^{N} \left[speed_{experiment,k}(i) - speed_{simulation,k}(i) \right]^2}{N}} \quad (9)$$

where
e_k is the rms error for each armature voltage k
N is the number of data used for both testing and simulation

In this paper, the number of armature voltage used for searching is equal to 5 inputs (60, 100, 160, 200, and 220 V). Therefore, the cost value (W) for ATS algorithm can be calculated by

$$W = \frac{\sum_{k=1}^{m} e_k}{m} \quad (10)$$

where
W is the cost value for ATS algorithm
m is the number of the inputs that are used for searching

According to (10), the objective of the ATS method is to search the machine parameters until a minimum W is obtained.

5. Searching results from ATS method

The six parameters in (8) can be determined from the ATS method and these parameters are given in Table 1.

Table 1. Machine parameters from ATS method

parameters	values
$R_a\,(\Omega)$	11.3518
$R_f\,(\Omega)$	590.1448
$L_a\,(\text{H})$	0.1677
$J\,(\text{kg.m}^2)$	4.5257e-006
$B\,(\text{Nm.s/rad})$	5.5345e-005
$K\,(\text{Nm/A})$	0.0313

The comparison between the $Speed_{(simulation)}$ and $Speed_{(experiment)}$ is addressed in Figure 5. It can be seen that the speeds of each armature voltage input when we use the machine parameters in Table I are nearly the same as those of the testing.
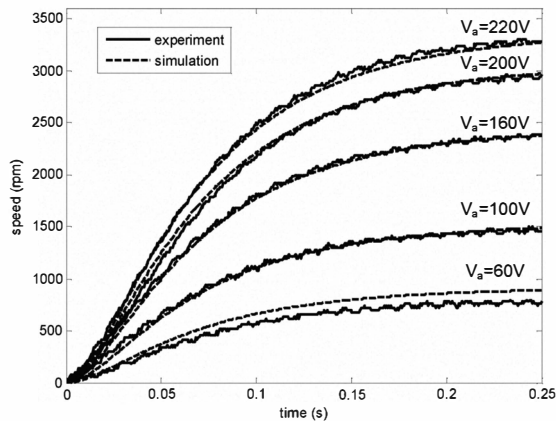
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Figure 4. The comparison between the speed responses from simulation and testing

The research work in [9] reported that the ATS method can escape the local solution to achieve the better solution. To support the work in [9], the results in Figure 5 also show the convergence of ATS for this problem. It can be seen that the ATS method can escape the local point to the better W value.
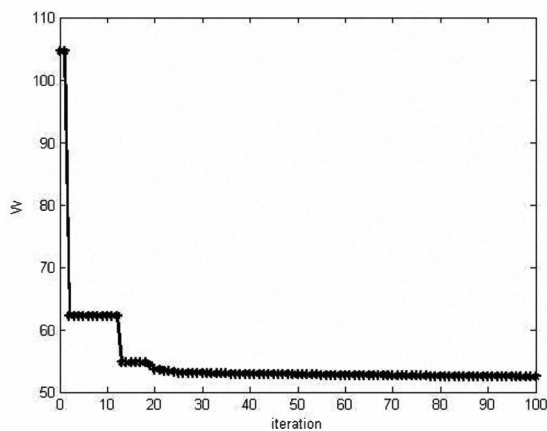

Figure 5. The convergence of W

6. Conclusion

Normally, the parameters of DC machine can be determined from the testing. However, the testing for some parameters is very complicated. As a result, the model provides some error because of the incorrect parameters in the model. Therefore, this paper presents how to apply the ATS technique to identify the machine parameters. The motor speeds of each

armature voltage from the experiment are used in the searching process. The paper shows that the mathematical model with the parameters from ATS method can obtain the speed response ($Speed_{simulation}$) nearly the same as those of the testing ($Speed_{experiment}$). Hence, the good agreement of the speed responses is to confirm that the parameters from the proposed method are correct. From the results, it also shows that the application of ATS method to the system identification is very useful for engineers. For the future work, other algorithms such as genetic algorithm or particle swarm optimization will be used to determine the DC motor parameters. The results will be compared with those of ATS method from this paper.

7. References

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