Permanent Magnet Brushless DC Motor optimal design and determination of optimum PID controller parameters for the purpose of speed control by using the TLBO optimization algorithm

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Abstract

Due to the important advantages of brushless DC motors such as small size, high efficiency, good torque, fast response, long life, quiet operation and lack of maintenance, these motors are used in many different areas. Medical industries, aerospace, electrical traction, hard disks, military equipment and automation instrumentation applications are included. So far, researchers have studied extensively such issues as optimal design, speed control systems and methods to reduce the torque ripple of this motor. Meanwhile, the optimal motor design in order to decrease the construction costs and loses as much as possible and also using an appropriate speed control system is specially important such that the motor speed response to load changes is as fact as possible. The present research aims to optimize the brushless DC motor in order to decrease the size and construction cost and simultaneously to design the optimal speed control system by using a proportional- integrator- derivative controller to increase the system's response rate to load changes. To reach these goals, first the motor in question is fully explained. Then the motor's specifications are expressed as a function of its geometry. The cost function combines mortality, volume, construction cost, overshoot percentage, rise time, and the motor speed response settling time that must be minimized simultaneously. To optimize the problem parameters, the new teaching- learning- based algorithm is used for the first time due to the power of this algorithm in finding the optimum solution of problems with large number of parameters and constraints and lack of sensitivity to the initial setting of parameters.

Key words: Optimal design, Speed control system, Cost function, PMBLDC motor, TLBO algorithm

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1. INTRODUCTION

The present research aims to find an appropriate optimal scheme for the construction of a Permanent Magnet Brushless DC Motor (PMBLDC) in order to decrease the overall motor size and its construction size and simultaneously to design an appropriate speed controller to obtain the desired motor specifications. From the standpoint of designing the optimal motor structure, the optimal design refers to a design in which the motor is designed at an appropriate output torque so that it has low weight and size, low loss and minimum cost. Similarly in terms of speed control, an appropriate speed control system is a system whose output speed response to the reference speed is as fast as possible in the presence of load changes (load torque) so that the motor can compensate the low speed due to load apply (fixed and variable) at the minimum amount of time. First the motor specifications are expressed in terms of mathematical equations obtained from the motor geometry. Then the effective parameter on the optimal design is extracted to be considered as the problem optimization parameters. In the speed control section, is related to speed as the output and refrence rate which is the input the transfer function which of system is expressed in the presence of load torque by using the dominant motor relations. The system's speed control is done by using a proportional controller - Integrator - derivative in the forward direction of the system's control structure. Since the problem of the optimal structure design and the Brushless DC Motor optimal design is a Multi-Objective one and the number of the fee function’s terms is large, a powerful optimization problem is required in solving Multi-Objective problems with multi-constraints. To this end, this paper used the new Teaching-Learning-Based Optimization (TLBO) algorithm due to its ability of solving multi-objective problems with multiple constraints, multiple dimensions and lack of sensitivity to the initial values of the algorithm parameters than other optimization algorithms. In [1], a method of optimal design for minimization of force ripple and maximization of thrust force in linear brushless permanent magnet motor (BLPMM) without finite element analysis is represented. The optimal design method consists of two steps. Step one is process of minimization of force ripple and step two is a process of maximization of thrust force. By using the electric and geometric parameters of motor obtained by this method, force ripple is minimized and thrust force is maximized, linear BLPMM is developed and applied to long stroke and precision positioning system. In [2], using genetic algorithm, optimal design of these motors was presented for the first time. Characteristics of the motor are expressed as functions of motor geometries. The objective function is a combination of losses, volume and cost to be minimized simultaneously. Electrical and mechanical requirements (i.e. voltage, torque and speed) and other limitations (e.g. upper and lower limits of the motor geometries) are cast into constraints of the optimization problem. In [3,4], the fuzzy, PI controller for speed control of BLDC motor was presented. In [5], Brushless DC motor speed control system based on fuzzy PID controller, was presented. The fuzzy PID control has better static and dynamic performance, control accuracy also rises greatly compared with the traditional PID control. And finally in [6], adaptive factor was added to the optimizations performed, and the last thing that was done in BLDC motor speed control, speed control using adaptive fuzzy PID controller. It has a better performance than the methods used was found. First, we peresent the motor structure and related parameters. And subsections 2.2-

2.3 presents design and speed control characteristics of BLDCM based on its geometrical results, properties. In subsection 2.4, describes the TLBO algorithm. Section 3,4 and 5, are discussion and conclusion respectively.

2. MATERIALS AND METHODS

2.1. MOTOR STRUCTURE

In this section, mathematical modeling of BLDC motor based on geometrical characteristics of motor, is expressed. Figure 1, shows the structure of permanent magnet BLDC motor. The parameters that shown in this figure are given in table 1.

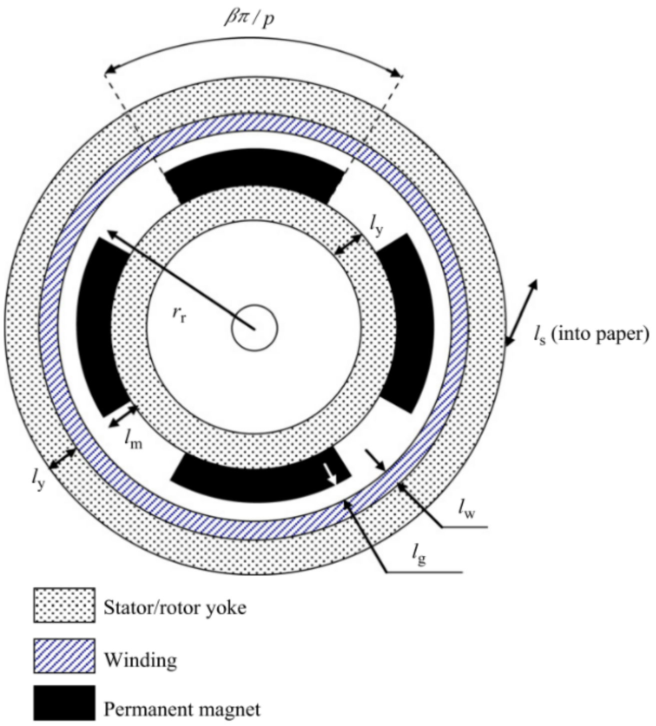

Figure 1: Structure of BLDC motor and Illustration of the key parameters.

Table 1 – Geometrical parameters of motor

P	number of pole pairs
β	pole–arc per pole–pitch ratio
l_m	magnet thickness
l_y	stator/rotor core thickness
l_w	winding thickness
l_g	mechanical air gap
r_r	rotor radius
J_{cu}	current density
l_s	wire gauge and stator/rotor axial length

2.2. DESIGN CHARACTERISTICS

2.2.1. ELECTROMAGNETIC TORQUE

Electromagnetic torque of motor based on its geometric characteristics is expressible by equation (1):

(1)

$$T_{em} = \frac{\pi k_f k_0 k_1 k_\beta B_r l_m l_s l_w (2r_r + 2l_g + l_w) J_{cu}}{\ln\left(\frac{r_r + l_g + l_w}{r_r - l_m}\right)}$$

k_1 and k_β, can be expressed using equations (2) and (3), approximately.

$$k_1 = 1 - \frac{1}{0.9\left[\frac{r_r}{\beta P (l_g + l_w)}\right]^2 + 1}$$

(2)

$$k_\beta = \frac{\alpha(\beta, k_c)}{k_c}$$

(3)

α is the span of the active coils located in the PM magnetic field at each instant (see Fig. 2), approximated by:

(4)

$$\alpha = \min(\beta, k_c)\,[k_s + (1 - k_s)\tanh(\delta|\beta - k_c|)]$$

Where $k_s \ll 1$ and δ are empirical constants.

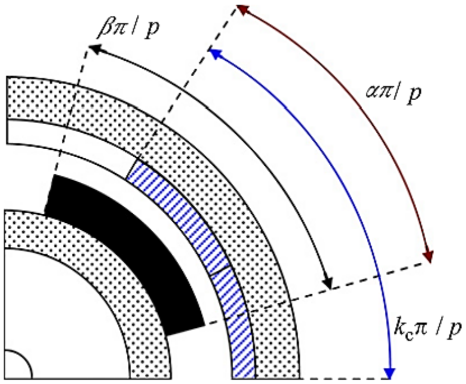

Figure 2: Concept of α.

2.2.2. COST OF MATERIALS

To incorporate the motor material cost into the optimization problem, it is required to relate the cost of those parts that are geometry dependent. Motor manufacturing cost can be written as:

$$C = c_{m1}\rho_m V_m + c_{m2}\rho + c_W(A_Q)k_f\rho_W V_W + c_y\rho_y V_t \quad (5)$$

Where ρ_m , ρ_w and ρ_y are the mass density of magnet, winding and stator/rotor core, respectively; c_{m1}, c_w and c_y are the cost per unit mass of magnet, wire and core materials, respectively. V_m, V_w and V_t denote the volumes of the magnet, winding and stator/rotor core, respectively. Having selected the type and thickness of laminations for stator/rotor core, the cost of core materials can be found by knowing the cost per unit mass, c_y. Total volume of motor is redefined as:

$$V_t = \pi l_s(r_r + l_g + l_W + l_y)^2 \quad (6)$$

2.2.3 POWER LOSS AND EFFICIENCY

In general, power loss of an electric motor can be divided into three categories: electrical, magnetic and mechanical. The power loss due to resistance of windings is considered as the most important electrical loss, which can be represented by:

$$P_{cu} = \rho k_f k_{et} k_o A_w l_s J_{cu}^2 \qquad (7)$$

The stator core maximum flux density due to PM can be expressed as:

$$B_{sy} = \frac{\pi \beta k_l B_r l_m}{2P t_y \ln\left(\frac{r_r + l_g + l_w}{r_r - l_m}\right)} \qquad (8)$$

Having calculated the constants, k'_h, *n* and k'_e, from volume of the stator yoke and material mass density, ρ_y , the following expressions are obtained:

$$P_h = k'_h \rho_y V_{sy} B^n_{\max} f^2 \qquad (9)$$

$$P_e = k'_e \rho_y V_{sy} B^2_{\max} f^2 \qquad (10)$$

Where frequency is easily related to the rotational velocity as $f = \frac{P\omega_r}{2\pi}$ and V_{sy} is the stator core volume. The mechanical losses such as windage, ventilation and bearing friction are put into the last category. The friction of bearings is proportional to radial load of the bearing, F_b , inner diameter of the bearing, d_i , friction coefficient of the bearing, μ_f , the number of bearings, N_b, and rotational speed of the rotor, ω_r. It is almost independent of motor geometry and defined as:

$$P_b = \frac{N_b}{2} \mu_f F_b d_i \omega_r \qquad (11)$$

Although windage losses depend on the rotor parameters, it is negligible compared with other losses for a smooth cylindrical rotor. It can be defined as:

$$P_W = \pi k_r c_f \rho_{air} \omega_r^3 r_r^4 l_s \qquad (12)$$

Where k_r is the roughness coefficient of the rotor (for smooth rotor $k_r = 1$), ρ_{air} the air density and c_f the friction coefficient, which is obtained by the following expression:

(13)

$$c_f = \begin{cases} 0.5150 \dfrac{\left({l_g}/{r_r} \right)^{0.3}}{R_e^{0.5}} & for \ \ 500 < R_e < 10^4 \\ 0.0325 \dfrac{\left({l_g}/{r_r} \right)^{0.3}}{R_e^{0.2}} & for \ \ R_e > 10^4 \end{cases}$$

Where $R_e = {\rho_{air} \omega_r r_r l_g}/{\mu_{air}}$ is the Couette–Reynolds number and μ_{air} shows the dynamic viscosity of air. Considering the magnetic losses, the developed torque is modified as:

(14)

$$T_{em} = \frac{\pi k_f k_c k_t k_\beta B_r l_m l_s l_w (2r_r + 2l_g + l_w) J_{cu}}{\ln\left(\dfrac{r_r + l_g + l_w}{r_r - l_m} \right)} - \frac{P_e + P_h}{\omega_r}$$

And the output torque is expressed as:

(15) $$T_{out} = T_{em} - {(P_w + P_b)}/{\omega_r}$$

And total losses of is expressed as:

(16) $$P_L = P_{cu} + P_h + P_e + P_b + P_w$$

2.4. SPEED CONTROL SYSTEM

The PID controller, due to advantages such as simplicity, durability, reliability and easy tuning parameters is widely used in industrial applications. The conventional PID control structure used is shown in Figure 3. The standard PID controller calculates the difference e(t) between the reference value and the actual one. Then, the BLDC motor control signal system is controlled by the u(t) signal and a linear combination of the proportional, Integrator and Derivative components.

The PID control law corresponding to Figure 3 is expressed as the relation (16).

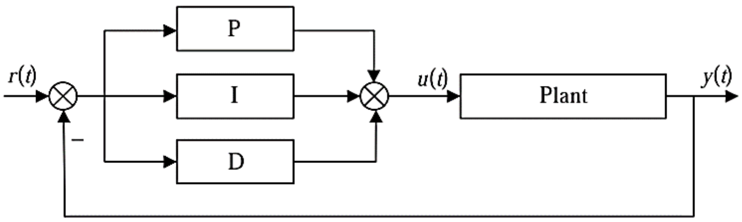

Figure 3: PID control system diagram.

(16)

$$u(t) = K_{\mathrm{P}}\left(e(t) + \frac{1}{T_{\mathrm{I}}}\int_{0}^{t} e(t)\mathrm{d}t + T_{\mathrm{D}}\frac{\mathrm{d}e(t)}{\mathrm{d}t}\right)$$

Where K_P = Proportional gain, T_I = the integral time constant and T_D is the derivative time constant.

The BLDC motor transfer function is expressed as equation (17) [7]:

(17)

$$\begin{aligned}\Omega(s) &= G_{\mathrm{u}}(s)U_{\mathrm{d}}(s) + G_{\mathrm{L}}(s)T_{\mathrm{L}}(s)\\ &= \frac{K_{\mathrm{T}}U_{\mathrm{d}}(s)}{L_{\mathrm{a}}Js^2 + (r_{\mathrm{a}}J + L_{\mathrm{a}}B_{\mathrm{v}})s + (r_{\mathrm{a}}B_{\mathrm{v}} + k_{\mathrm{e}}K_{\mathrm{T}})} - \frac{(r_{\mathrm{a}} + L_{\mathrm{a}}s)T_{\mathrm{L}}(s)}{L_{\mathrm{a}}Js^2 + (r_{\mathrm{a}}J + L_{\mathrm{a}}B_{\mathrm{v}})s + (r_{\mathrm{a}}B_{\mathrm{v}} + k_{\mathrm{e}}K_{\mathrm{T}})}\end{aligned}$$

That is implementable as figure 4.

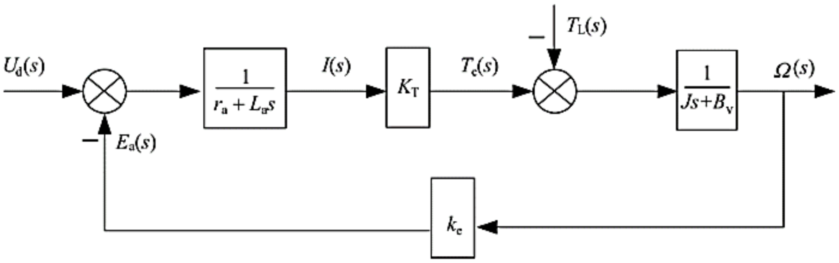

Figure 4: Structure of BLDC motor with load torque.

According to figures 3 and 4, the diagram of BLDC motor speed control system is displayed in figure 5.

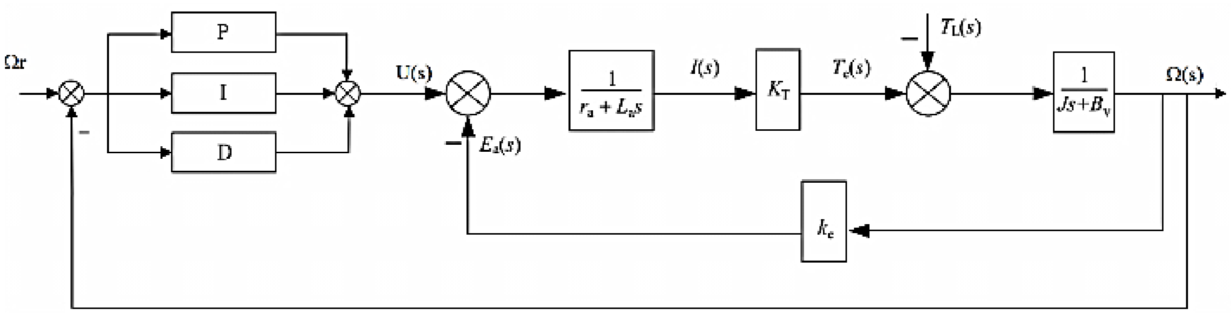

Figure 5: Diagram of BLDC motor speed control system using PID control.

In this figure, $\Omega(s)$ is the the response speed to the reference speed [7].

2.5. TLBO OPTIMIZATION ALGORITHM

TLBO algorithm is a powerful and effective search algorithm. The main idea of this algorithm that is an evolutionary algorithm is the simulation process taught in the traditional classroom. This fledgling new algorithm was introduced for the first time by Rao (2012) for solving constrained and non-constrained optimization problems with real parameters. Rao and Patel (2012) presented the elitist TLBO algorithm for solving constrained optimization problems. Of the important advantages of this algorithm is that it needs afew optimization parameter valued in compare with other common algorithms. Therefore just general parameters such as the population size, number of generations, stop criterion used in all optimization algorithms. This algorithm is very powerful and capable of being implemented on various optimization problems such as single-objective, multi-objective, multi-constrained, no constraint, linear and nonlinear as well as very high dimensional problems [8]. The overall performance of the algorithm is summarized in two main phases: the teacher phase and the student phase.

2.5.1. TEACHER PHASE

In this phase the solution nominations are randomly distributed throughout the search space. Thus, the best solution will be selected amongst all and will interact the knowledge with other candidates. Elaborately, since a teacher, who is the most skilled person about the objective in the population, influences the student's deed to take part some pre-planned aim. It is desired that the teacher augments the mean of his or her class information level depending on his or her experience. The teacher, thus, will put maximum effort into training his or her learners.

The mean parameter m^g of each subject of the learners in the class at gth generation is given as:

(18)

$$M^g = [m_1^g, m_2^g, \dots \dots, m_j^g, \dots \dots, m_D^g]$$

The learner with the minimum objective function value is considered as the $X^g_{Teacher}$ for respective iteration. The Teacher phase makes the algorithm proceed by shifting the mean of the learners towards its teacher. To obtain a new set of improved learners a random weighted differential vector is formed from the current mean and the desired mean parameters and added to the existing population of learners. This equation expressed is as:

(19)

$$Xnew^g_{(i)} = X^g_{(i)} + rand \times (X^g_{Teacher} - T_F M^g)$$

T_F is the teaching factor which decides the value of mean to be changed. Value of T_F can be either 1 or 2. The value of T_F is decided randomly with equal probability as:

(20)

$$T_F = round[1 + rand(0,1)\{2 - 1\}]$$

It may be noted here that T_F is not a parameter of the TLBO algorithm. The value of T_F is not given as an input to the algorithm and its value is randomly decided by the algorithm using Eq. (20). After conducting a number of experiments on many benchmark functions it is concluded that the algorithm performs better if the value of T_F is between 1 and 2. If $X^g_{new(i)}$ is found to be a superior learner than $X^g_{(i)}$ in generation g than it replaces inferior learner $X^g_{(i)}$ in the matrix.

2.5.2. LEARNER PHASE

In this phase the interaction of learners with one another takes place. The process of mutual interaction tends to increase the knowledge of the learner. The random interaction among learners improves his or her knowledge. For a given learner $X^g_{(i)}$, another learner $X^g_{(r)}$ is randomly selected($i \neq r$). The i^{th} parameter of the matrix *Xnew* in the learner phase is given as:

$$Xnew^g_{(i)} = \begin{cases} X^g_{(i)} + rand \times \left(X^g_{(i)} - X^g_{(r)}\right) & if\ f\left(X^g_{(i)}\right) < f(X^g_{(r)}) \\ X^g_{(i)} + rand \times \left(X^g_{(r)} - X^g_{(i)}\right) & oterwise \end{cases} \quad (21)$$

3. RESULTS

3.1. COST FUNCTION

Of the innovative aspects of this paper is the fee function used. In this paper, the BLDC motor design optimization problem is considered for the first time as well as the problem of obtaining the optimal motor speed control system by using the PID controller simultaneously. In other words, the cost function used was a combination of the optimal motor design features and the parameters of the motor speed control system. The speed control system implemented in the optimization problem is shown in Figure 5. The constant parameters of this structure are presented in table 2. Relations (16), (5), (6) and (15), respectively, are related to the overall motor losses (W), the total the motor construction cost (£), the total motor size (m^3) and the output torques (Nm) that should be considered in the optimal motor design. Also, the optimal design parameters are presented in table 2. The variables of the optimization problem are expressed as relation (22):

$$X = [P\ \beta\ l_m\ l_y\ l_w\ l_g\ l_s\ \tau_p\ \lambda\ A_c\ J_{cu}\ k_p\ k_i\ k_d] \qquad (22)$$

Among which the first 11 parameters are related to the optimal BLDC motor design whose brief definition is presented in table (1), while the last 3 ones are related to the motor speed control system (PID controller parameters). Thus, in total, there are 14 different parameters by the optimization of which the optimization algorithm must minimize the cost function.

Table 2 – The list of constant parameters and values

value	parameter	value	parameter
1000	σ	0.7	k_f
7400	$\rho_m\,(kg\ m^{-3})$	0.66	k_c
8900	$\rho_w\,(kg\ m^{-3})$	0.95	k_s
7700	$\rho_y\,(kg\ m^{-3})$	5	δ
20	$c_{m1}\,(£\ kg^{-1})$	1	$B_r\,(T)$
1	$c_{m2}\,(£)$	1.5	$B_{sy}^{kmax}\,(T)$
3	$c_y\,(£\ kg^{-1})$	10^11	$k\,(A^2 m^{-3})$
0.045	$c_1\,(£\ mm^2\ kg^{-1})$	1.8*10^8	$\rho\,(\Omega m)$
5.42	$c_2\,(£\ kg^{-1})$	0.018*	$k'_h\,(W\ s\ kg^{-1} T^{-n})$
10	$T^*_{em}\,(Nm)$	0.00008*	$k'_c\,(W\ s^2\ kg^{-1} T^{-2})$
4.31	$R_s\,(\Omega)$	1.192*	n
2.758	$L_s\,(\mu H)$	0	$k'_e\,(W\ s^{1.5}\ kg^{-1} T^{-1.5})$
11*10^-6	$J\,(kg\ m^2)$	1	γ
100	N	0.2	ε

(*For M19 lamination with thickness of 0.35 mm.

The structure of the fee function is as relation (23).

(23)

$$f_o(X) = w_p P_1(X) + w_v V_t(X) + w_c C(X) + \frac{1}{\varepsilon}\begin{bmatrix} f_u\left(1 - {T_{em}}/{T_{em}^*}\right) + f_u\left(1 - {\omega_r^{max}}/{\omega_r^*}\right) \\ + f_u\left(\frac{B_{sy}}{B_{sy}^{knee}} - 1\right) \end{bmatrix} + w_{ov}\mathrm{OV}(X) + w_{rt}\mathrm{RT}(X) + w_{st}$$

Where w_p , w_v and w_c are weighting factors, P_1 is the sum of the electrical, mechanical and magnetic power losses, V_t the total volume of the motor and C the cost of the materials used in the motor. f_u in (23) defined as:

(24)

$$f_u(x) = \frac{1}{1 - e^{-\sigma x}}$$

Where ε is a small and σ is a large constant.

w_{ov}, w_{rt} and w_{st} are the weight coefficients of the maximum overshoot, the rise time and the settling time of the motor control system response, respectively. Also $\mathrm{OV}(X)$, $\mathrm{RT}(X)$ and $ST(X)$ are the function related to the calculation of the maximum overshoot, rise time and the response settling time for the optimization parameters vector X, respectively. It should be mentioned that certain relationships related to the speed control system should be changed based on the optimal design values. Thus, optimum motor speed response properties depend on the optimal values of the design section. In other words, changes in the design specifications affects the speed response. Therefore, the relations (25), (26) and (27) exist.

(25)

$$\mathrm{B_Y} = \mathrm{B_{sy}}$$

(26)

$$\mathrm{k_T} = \mathrm{k_e} = 4\mathrm{PNSB_{sy}}$$

Where P is the number of pairs of poles, N is the number of the winding and S is the rotor radius multiplied by the effective length of the conductors.

(28)

$$S = r_r \times l_s$$

3.2. TLBO ALGORITHMS IMPLEMENTATION AND COMPARISON

The necessary parameters to execute the TLBO, GA, PSO and ICA algorithms are presented in table (3). Table (4) shows the weight coefficients of the fee function aimed to reduce the size and increase the system's response rate. The reference speed and the load torque are 10 RPM and 1Nm, respectively.

Table 3: Parameters required for the implementation of the GA, PSO, ICA, TLBO algorithms

value	parameter	
100	Number of the initial population	GA
2	Number of elits	
0/8	Crossover rate	
0/2	Migration rate	
50	Iteration	
100	Number of the initial population	PSO
0/9	W	
2	C_1, C_2	
50	Iteration	
100	Number of the initial population	ICA
10	Number of imperialism	
1	Revolution rate	
50	Iteration	
100	Number of learners	TLBO
50	Iteration	

Table 4: Parameters required for the implementation of the TLBO algorithm

100	Number of population
50	Iteration
1	W_p
100	W_v
1	W_c
1	W_{ov}
1	W_{rt}
100	W_{st}

As it is seen in table 3, the only parameters that must be valued in the TLBO algorithm are the number of population and the number of repetitions. After applying these parameters and during the generations required for the implementation of the algorithms, figure (6) shows the best response for each generation for the 4 above-mentioned algorithms (TLBO, PSO, GA, ICA). Also figure (7) shows the speed response for the optimization of the mentioned algorithms.

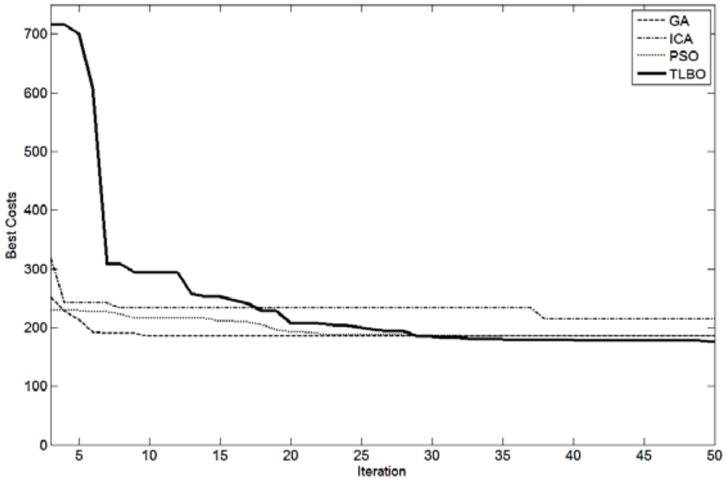

Figure 6: The best cost for each generation for the 4 algorithms (TLBO, PSO, GA, ICA).

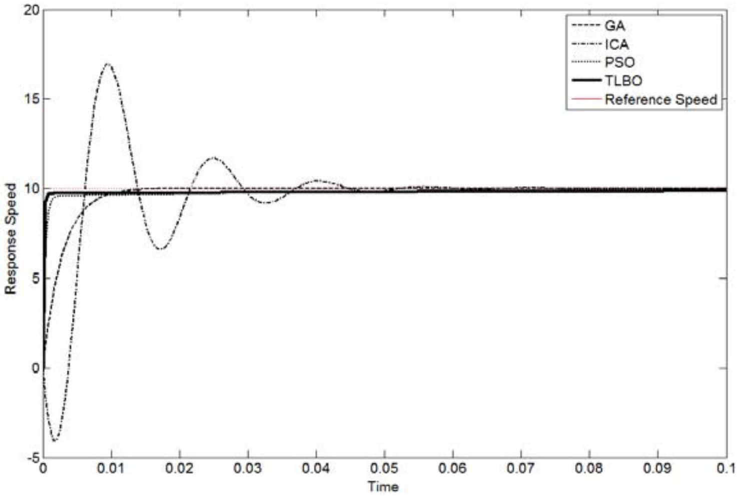

Figure 7: Speed response for the optimization of the algorithms (TLBO, PSO, GA, ICA).

As it is seen in figure 7, the optimized system's speed response with the GA algorithm begins at zero and follows the reference speed, while the optimized system's speed response with the ICA suffers from poor conditions. First it drops off quickly and then starts following the reference speed that is associated with a high overshoot. However, the response speed of the algorithm PSO, has a much better situation than these two algorithms, respond where the speed response reaches the final value quickly without overshoot. Finally as expected, the system designed by the TLBO algorithm is much better than all of the above-mentioned algorithms such that the speed response starts following the reference speed without drop off and reaches the final value faster than other algorithms. All details pertaining to simulations performed are presented in table 5.

Table 5: Characteristics of optimal algorithms for the optimization problems with GA, PSO, ICA, TLBO

Cost	Optimal speed control system Characteristics			Optimal design Characteristics				
	MAX OV.Sh(%)	Rise time(sec)	Settling time(sec)	Total losses(W)	Total volume(m^3)	Total cost(£)	Output torque	
185.2	0	0.006	0.0088	108.8	0.0014	75.2	10.1	GA
184	0	0.0008	0.016	106.3	0.0015	77.8	10	PSO
215	69.4	0.01	0.035	126.2	0.0015	78.1	11.1	ICA
175.8	0	0.0004	0.0008	101.3	0.0013	73.3	10.1	TLBO

As seen in table 5, the settling time of the system's response speed optimized with PSO and TLBO algorithms is lower than GA and ICA. Also the overall motor size that must be as small as possible has better conditions in these two algorithms than GA and ICA. Construction costs, losses, overall size, rise time and the settling time of the TLBO algorithm are much better than other algorithms and even the PSO algorithm. In the conclusion o this comparison, we can say that the TLBO algorithm had the best answer as expected.

4. DISCUSSION

BLDC motors may be made in very small sizes that may be considered as the most important and effective issue in extending their applications. For this purpose, extensive attempts have been made for preparing the optimum layout for the construction of such motors with the minimum possible size and the minimum construction cost. In 2010 and in [10], for the first time, the optimum design of BLDC motor was introduced by using the genetic optimization algorithm. Power losses, the overall motor size and its construction cost were of the optimized parameters in [10] where the weight coefficients were determined aimed to reduce the motor size. The optimized design was with size $1.164 \times 10^{-3}\ m^3$, construction cost of 68.86 Euros and the total loss of 56.71 watts. In this paper, according to [10] and the results, the BLDC motor optimal design and its speed control issues by using PID controller were studied. As it is seen in table (5), the size, construction cost and the motor losses are higher than the values obtained in [10]. It should be mentioned that some on optimized design parameters affect the optimization of the speed control system. In other words, the optimization algorithm should consider some parameters to obtain the optimum design and optimum speed control system. Thus, it is possible that the power losses and construction costs with smaller weight coefficients in table (4) are out of acceptable range to achieve the optimum control system's properties. For instance, power losses is doubled in comparison with the values obtained in [10] that may not be desirable, but since the goal of optimization is to increase the speed of response of the system besides decrease size and construction cost, increased losses may be partially ignored.

5. CONCLUSION

For the first time, this paper studies simultaneously the optimal design and optimization of the PMBLDC which is a multi-objective problem with many parameters and optimization constraints aimed to introduce the important advantages and extensive applications of such motors in various areas. Clearly according to the application range of the motor, the motor must be supplied according to the consumer market needs. For example, in the medical industry, the most important factor in the use of medical devices that help the patients are the device's size and weight. In this paper, the TLBO optimization algorithm is used for the first time due to the ability of the algorithm to solve problems with a large number of parameters and many constraints. An important feature of this algorithm is that it is not necessary to set specific parameters like other optimization algorithms that lead to its fast and simple implementation. The results of this study can be categorized as follows:

1. To find The cost function contains design and speed control problem of BLDCM for the first time.
2. To find the optimum design characteristics and PMBLDC optimum motor speed control system simultaneously aimed to reduce the size and increase the response speed of the system to reach the steady state.
3. To demonstrate the efficiency of the TLBO algorithm in solving the optimum design problem and the PMBLDC motor speed control system optimization that is a multi-objective problem with a large number of parameters and constraints.

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