Порівняння генетичного та імунного алгоритмів під час оптимізації одного двигуна з типовим аксіальним магнітним потоком

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Двигуни з постійними магнітами широко використовуються в промисловості через їх високу ефективність і невеликі розміри. Двигуни з типовим аксіальним магнітним потоком представляють нове покоління двигунів з постійним магнітом і вони здебільшого використовуються як рушійна сила електричних транспортних засобів. Вперше саме в цій роботі запропоновано рівняння, пов'язані з розробкою одного безпазового двигуна з типовим реверсивним аксіальним магнітним потоком. Запропоновані рівняння використовувалися для того, щоб оптимізувати функцію мети енергетичної концентрації. Оскільки ці двигуни широко використовуються в електричних транспортних засобах, співвідношення потужність/об'єм є дійсно важливим. Дуже бажаною є більша потужність у меншому розмірі, тому розробляються транспортні засоби з такою характеристикою.

Генетичний та імунний алгоритм використовувалися для того, щоб оптимізувати функцію мети. Схема процесу і технологія оптимізації є ті ж самі для обох методів. У підсумковій частині роботи представлено результати дослідження, а також порівняно швидкість і результати двох методів. На їх основі можна стверджувати, що імунний алгоритм є набагато кращим, ніж генетичний алгоритм в оптимізації цього виду двигунів. Імунний алгоритм відбувається відносно швидше і має кращі результати щодо оптимізації функції мети, ніж генетичний алгоритм.

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A comparison of genetic algorithm and immune algorithm in optimization of one typical axial flux permanent magnet motor

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Permanent magnets motors are widely used in the industry due to their high efficiency and their small sizes. Axial flux permanent magnet motors are new generation of permanent magnet motors and they are mainly used as propulsion of electrical vehicles. First in this paper, equations which are related to design of one typical slot less bidirectional axial flux motor have been proposed. These equations have been used in order to optimize key parameters of motor with two optimization methods: genetic algorithm and immune algorithm. Finally results have been presented and one can see that immune algorithm is better than genetic algorithm in optimization of this kind of motor.

Keywords – axial flux permanent magnet, immune algorithm (CSA), genetic algorithm (GA)

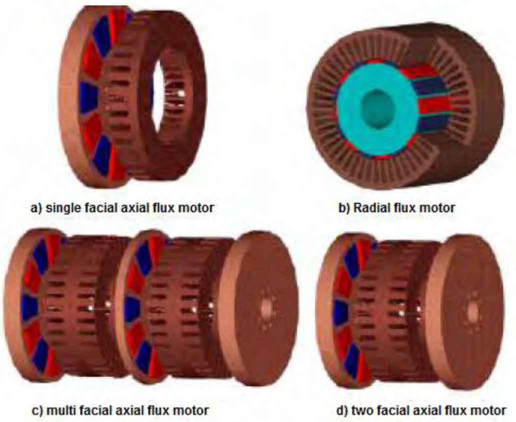
I. Introduction

Axial flux permanent magnet motors are one of the most important elements of electrical vehicles industry. So optimization of these motors have key role in the optimization of electrical vehicles. Permanent magnet motors mainly are categorized in two main branches of axial flux permanent motors (AFPM) and Radial flux permanent magnet motors [2]. In the axial flux permanent magnet motor, flux path is parallel with the shaft and it is the main difference of this kind of motors with the conventional motors. Axial flux motors have single facial, two facial and multi facial constructions [2], [4]. Among these various kinds, two facial constructions have the best performance and so are the most popular constructions. Also, axial flux motors are separated in two slotted and slot less categories. Slot less category has some advantages over slotted category. For example in the slot less category, flux distortion, core loss, tooth distortion and vibration have been omitted [1].

In this paper, equations for designing one typical two facial and slot less axial flux permanent magnet motor have been proposed. After that, immune and genetic algorithms have been used for optimization of the introduced motor. The goal function for these motors is power destiny. Because these motors are used in the electrical vehicles and in the electrical vehicles the most important parameters is power per volume [4]. The more power per volume, the better motor we have. Note that this kind of motor typically has high efficiency and choosing efficiency as goal function is not rational. By comparing results of these two methods, we found out that immune algorithm is better in optimization of axial flux permanent magnet motors.

II. Axial flux permanent magnet motors

Axial flux permanent magnet motors have single facial, two facial and multi facial constructions. Fig 1 shows these different constructions for slotted motors.



a) single facial axial flux motor

b) Radial flux motor

c) multi facial axial flux motor

d) two facial axial flux motor

Fig. 1. Different constructions of slotted motor

Slot less motors have similar construction. The only different is that in this motor there is no slot and so in this kind of motor we do not have teeth torque. Construction of Slot less motors has been showed in the Fig 2.

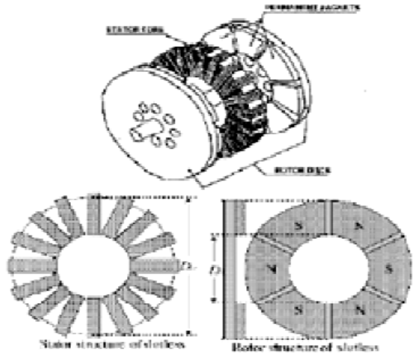


Fig. 2. Slot less axial flux motor

Fig 3 shows stator of one typical axial flux permanent magnet. If the current flows from down to up, the force to the rotor will be from the left.

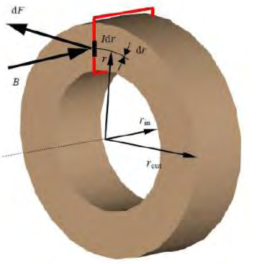


Fig .3. Torque production in axial flux motors

Fig 4 shows torque versus relative radius for this kind of motors. As it can be seen, if K_D=0.58 nominal torque of motor is close to the maximum torque. It is useful because with this graph designer can estimate maximum speed of his desired motor and he can use this speed in his calculation.

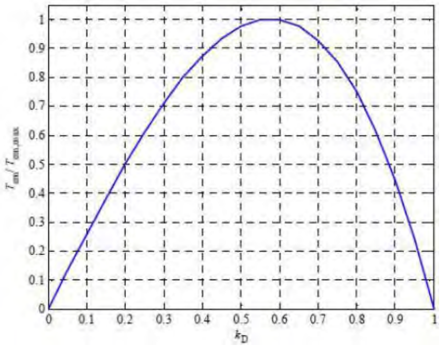


Fig. 4. Torque versus relative radius graph

For calculation of flux destiny in different places of the motor, we have used a non-linear reluctance model which is presented in the Fig (5). This Fig (5) shows reluctance model for each pole. R_y is reluctance of stator's yoke ,R_t is reluctance of the teeth, R_s is hole's reluctance and finally R_g is the sum of air gap's reluctances.

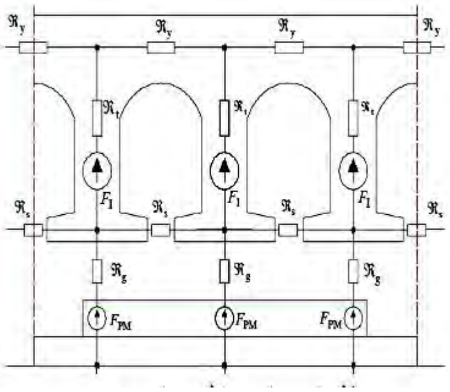


Fig. 5. Magnetic circuit model

In general, when leakage inductance and series resistance are negligible, output power will be calculated from equation (1).

$$P_{out} = \eta \frac{m}{T}\int_0^T e(t)\,i(t)\,dt = mK_p\eta E_{pk}I_{pk} \tag{1}$$

Where η is efficiency, m is the number of phases, T is period of current and E_{pk} is amplitude of EMF. K_p is obtained from the following formula:

$$K_p = \frac{1}{T}\int_0^T \frac{e(t)i(t)}{E_{pk}I_{pk}}dt = \frac{1}{T}\int_0^T f(t)_e f(t)_i dt \tag{2}$$

Where $f_i(t)$ and $f_e(t)$ are normalized functions of current and voltage, respectively.

E_{pk} is obtained from the following formula:

$$E_{pk} = K_e N_{ph} B_g \frac{f}{p}(1-\lambda^2)D_o^2 \tag{3}$$

Where K_e is a parameter which is depended on the distribution of windings. Also, N_{ph} is the number of turns per phase, f is the rotor frequency, P is the pole divided by two, D_o is the outer diameter of machine, B_g is the flux density in the air gap and D_i is the inner diameter of the stator.

For more accurate result, coefficient of current waveform has been defined as follow.

$$K_i = \frac{I_{pk}}{I_{rms}} = \left[\frac{1}{T}\int_0^T \left(\frac{i(t)}{I_{pk}}\right) dt\right]^{-0.5} \qquad (4)$$

Where I_{pk} has been defined as bellow:

$$I_{pk} = A\pi K_i \frac{1+\lambda}{2} \times \frac{D_o}{2mN_{ph}} \qquad (5)$$

With combination of equation (1),(3) and (5), one can obtain:

$$P_{out} = \frac{\pi}{2} K_e K_p K_i A B_g \eta \frac{f}{p}(1-\lambda^2)\left(\frac{1+\lambda}{2}\right) D_o^3 \qquad (6)$$

Where D_o is the outer diameter and can be obtained from the following formula:

$$D_o = \left(\frac{P_{out}}{\frac{\pi}{2} K_e K_p K_i A B_g \eta \frac{f}{p}(1-\lambda^2)\left(\frac{1+\lambda}{2}\right)}\right)^{1/3} \qquad (7)$$

Total outer diameter of stator can be obtained by equation (8).

$$D_{tot} = D_o + 2W_{cu} \qquad (8)$$

Where W_{cu} is defined as following equation:

$$W_{cu} = \frac{D_i - \sqrt{D_i^2 - \left(\frac{2AD_g}{K_{cu}J_s}\right)}}{2} \qquad (9)$$

In the above equation, K_{cu} is the accumulation factor, J_s is the current density and D_g is the average diameter of stator.

Total axial length (L_e) is defined as bellow:

$$L_e = L_s + 2L_r + 2g \qquad (10)$$

Where L_r is the length of rotor, g is the length of air gap and L_s the length of stator plus the height of windings from the stator.

$$L_s = L_{cs} + 2W_{cu} \qquad (11)$$

In the equation (11), L_{cs} is the thickness of stator yoke and can be obtained from the following formula:

$$L_{cs} = \frac{B_g \pi \alpha_p D_o (1+\lambda)}{4p B_{cs}} \qquad (12)$$

L_r can be obtained from the equation (13).

$$L_r = L_{cr} + L_{PM} \qquad (13)$$

Where L_{cs} is the thickness of rotor's yoke and can be obtained from the equation (12).

$$L_{cr} = \frac{B_u \pi D_o (1+\lambda)}{8p B_{cr}} \qquad (14)$$

B_u is the flux destiny in the surface of magnet and L_{pm} is the thickness of magnet. L_{pm} can be calculated from the equation 15.

$$L_{PM} = \frac{\alpha_r B_g}{B_r - \left(\frac{K_f}{K_d} B_g\right)}(g + W_{cu}) \qquad (15)$$

Where α_r is the relative permeability of magnet, B_r is the remnant flux density, K_f is the shape factor and K_d is the flux leakage factor.

III. Optimization process

The flowchart of optimization process has been proposed in the Fig 6. Equations which have been proposed in the previous pages, is used in the different parts of optimization process.

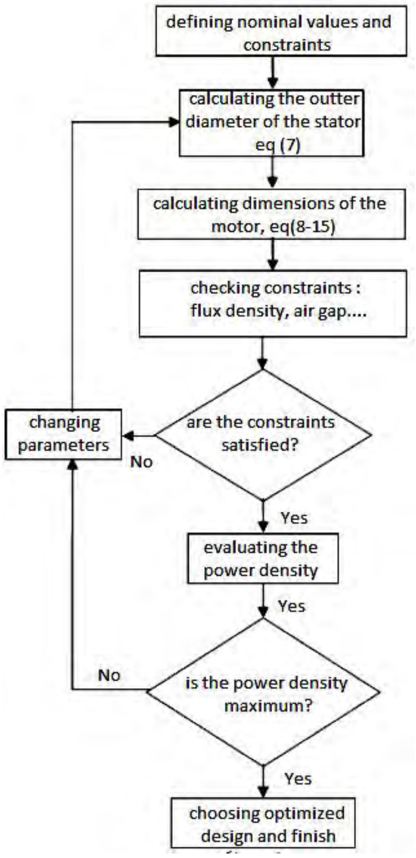


Fig. 6. Flowchart of optimization process

In this paper, motor has been optimized with two optimization methods. The immune and genetic algorithms are employed in order to optimize the goal function power density. We have compared results of two methods on the end of the paper. In our process optimization, our goal function is defined as bellow:

$$P_{den} = \frac{P_{out}}{\frac{\pi}{4} D_{tot}^2 L_e} \left({}^{W}\!/_{m^3}\right) \qquad (16)$$

Every optimization process has its own limitations. In designing such a motor, designer cannot choose any value for every parameter. In other word, designer has a list of limitations and all of parameters are not free. For example, designer cannot choose flux density more than about 1.2T. Because if he set flux density more than this number, motor can be saturated and it can causes many problems such as increase in loss. In this paper, we have employed real constraints which designer faces when he designs axial flux permanent magnet motors. Table (1) shows these constraints.

Table 1

Constraints of the optimization

Value	parameter
75KW	Nominal power
6	Number of poles
3	Number of phases
1.2T	Flux density in the rotor yoke
1.2T	Flux density in the stator yoke
90%	Efficiency
50HZ	Frequency
6 ($\frac{MA}{M^2}$)	Current density
1.2T	Magnet’s remnant flux

IV. Results

The results of two methods have been proposed in the table 2. As it can be seen, in the immune algorithm, value of the goal function is 3.5% more than the goal function in the immune algorithm. Also, immune algorithm is much faster than genetic algorithm. In the immune algorithm, goal function has been optimized after 50 irritations, while in the genetic algorithm the goal function has been optimized after 200 generation. These explanations also are shown in the Fig 7 and Fig 8.

Table 2

Results of optimizations

Parameters	GA	CSA
D_o	0.51	0.5
D_i	0.371	0.367
A (ampere per meter)	10502	10230
D_g	0.42	0.4
B_g	0.53	0.51
B_{CS}	1.193	1.199
B_u	1.011	1.0603
B_{cr}	1.194	1.1959
B_r	1.196	1.1985
g(m)	0.000101	0.0001007
P density(W per cm3)	1.99	2.06

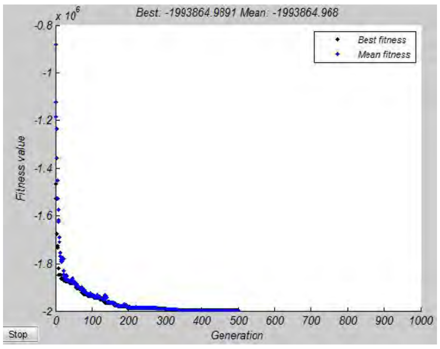


Fig .7. Genetic algorithm results

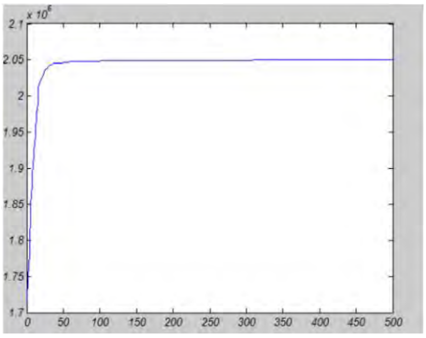


Fig. 8. Immune algorithm results

Conclusion

In this paper, one typical axial flux permanent magnet motor has been optimized by two different methods. Since axial flux permanent magnet motors are widely has been used in the electrical vehicles, we defined power density (power per volume) as our goal function. Results of two methods show that in optimizing such a motor, immune algorithm is better due to its better answer and its higher speed.

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