Efficiency Improvement of Induction Motor using Fuzzy-Genetic Algorithm

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Abstract

In most industrial zones, electric energy is one of the most important energy sources. Since electrical motors are the main energy consumers of industrial factories, consumption optimization in these motors can be considered as a main option related to energy saving. One very effective way to reduce the consumption of these equipment is to use a motor speed controllers or drives. Since the loss of inductive motor has a direct relationship with motor flux, in this paper, the rotor flux vector control has been used. Due to the strength of fuzzy controllers in load failure and noise generation states, this controller has been used to adjust the drive speed. Two fuzzy logic inputs including speed error and speed variation derivative, and a fuzzy output, motor reference torque (Te*) are estimated. The genetic optimization algorithm has been used in order to improve the Efficiency and reduce the losses. As such, the drive performance in GA and Fuzzy-Genetic (FG) states is reviewed and the simulation results are presented. Finally, the obtained results in this paper have been compared to the results of FOC inductive motor with PI controller and without optimization. It can be seen that when FG method is employed, the results show a higher performance and losses are reduced up to almost 40 to 50% in different loads, and the amount of input power is also reduced up to approximately 30%.

Keywords: Induction motor, Loss Minimization, Genetic algorithm, Fuzzy logic.

1. Introduction

Electric motors involve about 40% of the whole electric power consumption in the world. Widespread using of induction motors show that if their loss decreases to several percentages, it will play an important role in total power consumption in the world. Therefore, the motor efficiency is an inevitable approach of motor development [3]. Motor loss mostly relates to the control strategy and substantially acts in lower load time which is improved through optimized selection of the flux level [2]. Among the two strategies of flux level control,1- search control(SC) and 2- Loss Model control (LMC), LMC is faster and have no torque ripple. LMC has a disadvantage that is when the parameters change and in order to overcome this, online estimation of parameters was a good solution which is discussed in this paper. In this paper, a Fuzzy -Genetic loss reduction algorithm was used which was posed on the induction motor drive FOC

5hp. About 80% of the total losses are related to the copper and iron losses [1,7]. Hence, in this paper we focus on these two loss types which are totally known as electromagnetic losses. By appropriate adjustment of the magnetic flux, a proper balance between iron and copper losses is created in order to obtain the least electromagnetic loss. GA technique was used to reduce motor loss IM and therefore the efficiency would get the optimum and desired value by adjustment of the magnetic current. Simulation performance was performed in three states of FOC, GA and FG and compared with each other. The rest of the paper is organized as: in the next section the induction motor loss model is discussed, in sections 3, 3-1 and 3-2, proposed system, genetic optimization and Fuzzy controller are discussed, respectively. In section 4 , simulation results are discussed and conclusion is the last section.

1. Induction Motor Loss Model

In this paper an equivalent circuit which points out the rotor magnetic current is used. An iron loss resistance Rf was added in parallel with magnetic inductance in the rotor flux reference frame which is shown in figure.1 [2,5,7]. Information related to this machine is presented in Appendix 1.
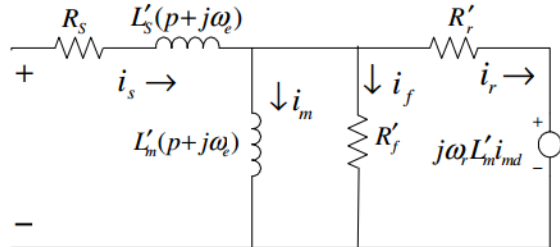

Fig. 1. Equivalent circuit of induction motor containing iron loss resistance
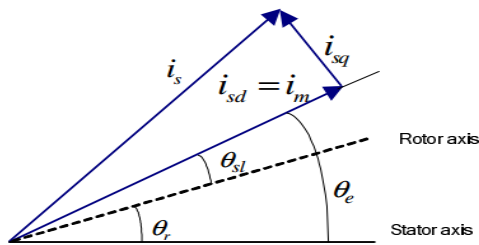

Fig. 2. Phasor diagram of the equivalent circuit and definition of rotor field angles[5]

In permanent state, there is no leakage inductance on the motor and the equivalent circuit will be the same as fig.3.

a)   Equivalent axis of axis d
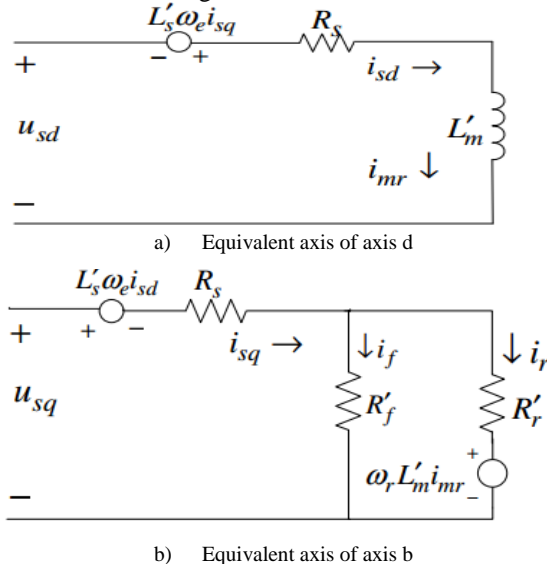

b)   Equivalent axis of axis b

Fig. 3. Motor equivalent circuit in the permanent state[5]

To develop the loss model, a typical simple approach has been discussed in the previous literatures [1,2,5].copper loss of stator, copper loss of rotor and iron loss which are totally stated as equation 1:

$$P_{total} = P_{cus} + P_{iron} + P_{cur}$$
$$= R_s(i_{sd}^2 + i_{sq}^2)$$
$$+ R'_f(i_{sq} + i_r) + R'_r i_r^2 \tag{1}$$

Where Pcus is the stator copper loss, Piron is the iron loss and Pcur is the copper loss of the rotor, when the voltage and stator currents are considered as the real variables, we need to obtain total loss in terms of isd and isq currents. From figure.3 the rotor current is obtained:

$$i_r = \frac{R'_f}{R'_f + R'_r} i_{sq} - \omega_r \frac{L'_m}{R'_f + R'_r} i_{sd} \tag{2}$$

By replacing equation 2 in equation 1, total loss is obtained:

$$P_{total} = R_d i_{sd}^2 + R_q i_{sq}^2 \tag{3}$$

Where ,

$$R_d = R_s + \frac{L'^2_m}{R'_f + R'_r} \omega_r^2 \quad , R_q = R_s + \frac{R'_f R'_r}{R'_f + R'_r}$$

Torque equation is:

$$T_e = \frac{3}{2} Z_p \frac{(L'_m i_{mr})^2}{R'_f + R'_r} \omega_{slip}$$
$$= \frac{3}{2} Z_p L'_m i_{mr} i_{sq}$$
$$- \frac{3}{2} Z_p \frac{(L'_m i_{mr})^2}{R'_f} \omega_e \tag{4}$$

In the permanent state we have:

$$i_{sq}(i_{sd}) = \frac{T_e}{K_t i_{sd}} \tag{5}$$

Equation 3 - loss relation is summarized as equation 6:

$$p_{total} = R_d i_{mr}^2 + R_q \frac{T_e^2}{K_t^2 i_{mr}^2} \tag{6}$$

2. The Proposed System

The diagram block of the proposed optimized approach is shown in fig.4. Motor control method was based on rotor flux vector control method (FOC). In this structure, speed and electromagnetic torque of the motor are measured to obtain magnetic current.
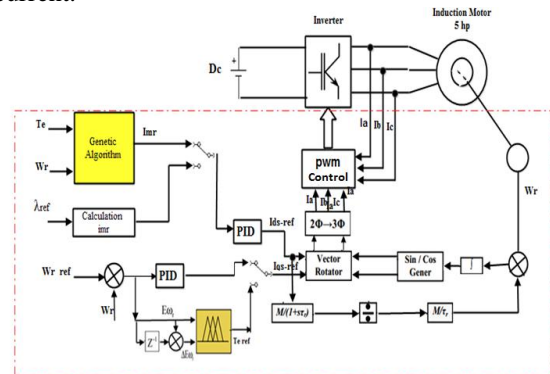

Fig. 4. The proposed approach

A) Genetic Algorithm Optimization Process

Optimization process includes searching   the optimized magnetic current rate by receiving torque and motor speed. Using this method needs a target function to address the best magnetic current. The target function is equation 6 ,   which affects the optimization process in form of equation 7.

Optimization process of the genetic algorithm is as follow:
- Generation of the initial random population
- Evaluation of the target function(equation 7)
- Reproduction: parents are of the highest target function to the lowest categorized value. The excellent individuals directly go to the next stage with no change.
- Crossover act and mutation (new children production)
- Return to stage 2
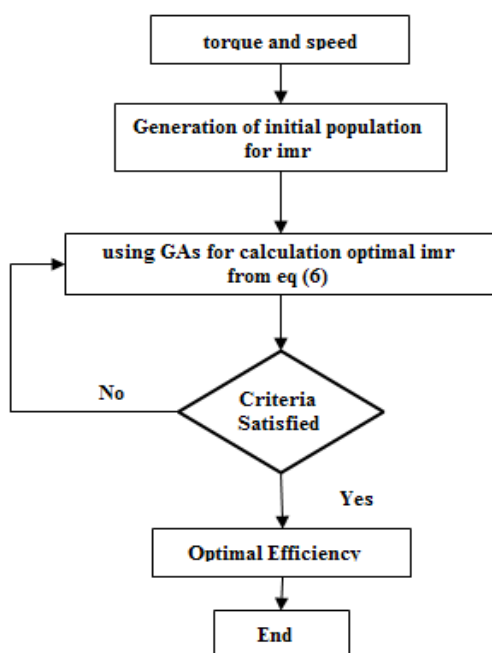 Optimization flowchart is shown as follow:

Fig. 5.   Optimization flowchart of genetic algorithm

B)   Fuzzy Control Structure

An FLC is the conversion of Linguistic expressions based on expert knowledge into the control strategy[9]. First , the speed error and its variation derivative are input as FLC variables. Then, FLC output variable is introduced as the reference value Te^*. then these numerical variables are converted into the Linguistic variables. Five fuzzy sets are seen in table.1 as NL(Negative large), NS(Negative small), Z(Zero), PS (Positive small) and PL(Positive large)[11-15].

Fuzzy control structure is defined as follow:

- Five fuzzy sets for each input and output variable
- Fuzzification by using continuous universe of discourse
- Using mamdani performance (min)
- Defuzzification by using centroid

Table.1.
Fuzzy rules set for the proposed system

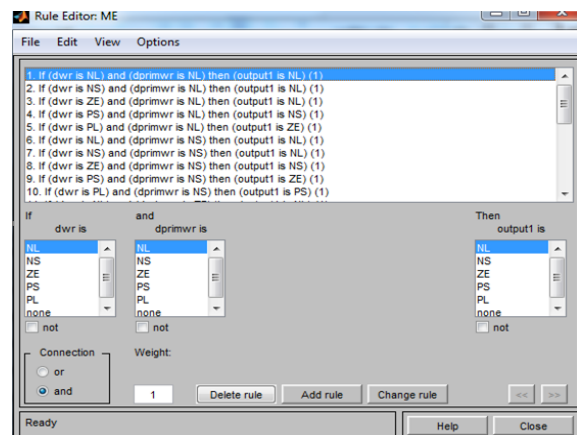| $\Delta\omega_r^*(k)$ / $\Delta\omega_r(k)$	NL	NS	ZE	PS	PL
NL	NL	NL	NL	NS	ZE
NS	NL	NL	NS	ZE	PS
ZE	NL	NS	ZE	PS	PL
PS	NS	ZE	PS	PL	PL
PL	ZE	PS	PL	PL	PL

Fig. 6.   Fuzzy rules

In table.1 , fuzzy rules are shown. According to Fig.6 it can be seen that the operator applied in the rules is And type and the output is also defined as a linear function. FLC structure is shown in fig.7. Fuzzy control structure (FLC)is similar to PID and in order to avoid integral operator problem in rule database, error differentiation was used and therefore there are error variables and variations in the rule database and the reference torque Te^* is in the output.
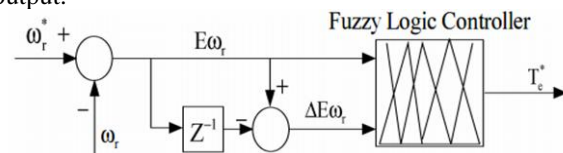

Fig. 7.   Fuzzy controller structure

After training and storage of fis file, the file was used in simulink. To do so , fuzzy controller block which calls Fis file information from the workspace has been used.

3. Results of Simulation with Fuzzy-Genetic Algorithm

As it was mentioned earlier, in this paper a 5-Hp induction motor simulation has been investigated based on the system model. Figure 9 shows the motor torque under the FG method. As it can be observed in from the figure, torque has a lower ripple than [4, 5, 6, 8 ,16] methods. Figures 9 to 13 show the result of the proposed approach simulation. After extracting the required data, losses were examined in various modes in order to test the designed system. The loss amount diagram is shown in figure 11. Figure 12, shows the amount of input power. The results of motor operation under 1 to 20 Nm motor are shown in three states of FOC, GA and FG.
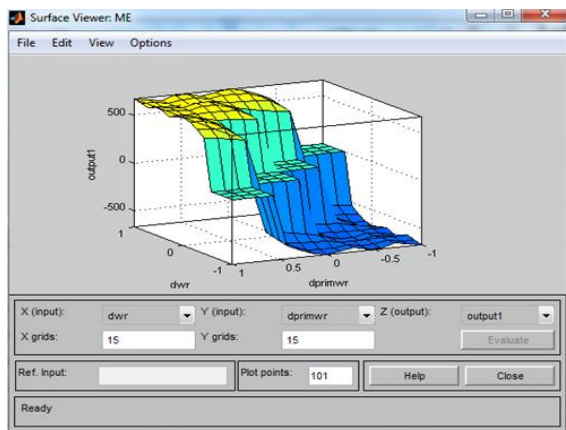

Fig. 8.   3D diagram of the system controller area

Figure 10 shows the amount of effective current (rms) of d axis, resulted from the genetic algorithm. As it is observable from the figure, as the load torque increases gradually between 0 and 20 Nm, the amount of d axis current increases. The nominal range of motor current is approximately between 0 to 8 Ampere. The 8Ampere current holds in its nominal mode, and this is the maximum applicable current on the motor. The genetic approach in figure 10 has been applied in accordance to the motor nominal
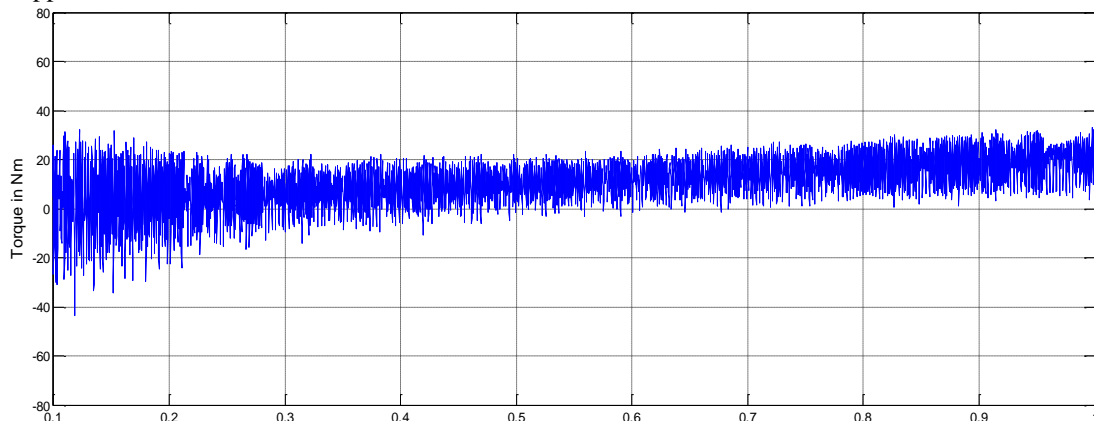
current. The loss optimization results in induction motor in 3 field control modes, FOC, GA and FG algorithm are shown in figure 11. In each point the mean loss is obtained in time interval of 0 to 1. For example, as can be seen in 10Nm torque point the losses vary in a constant amount, the average of which can yield the interested point. It can be concluded from figures 11 through 13 that the amount of losses, efficiency and input power in their nominal mode (TL = 20) are close to each other in all three methods. This means that genetic and FG optimization methods are considered in loads lower than the nominal load. In appendix 2 a summary of the proposed approach in comparison to the non-optimized method is presented. As can be seen from Appendix 2 table, using the proposed system we can achieve a 92% Efficiency in low-load conditions. Figures 11 and 12 show the motor start results under 1-20 Nm in three states FOC, GA and Fuzzy-GA.

4. Conclusion

In this paper a new fuzzy genetic system is presented to improve the Efficiency and decrease the losses. In order to increase the motor drive stability, during variations of speed and load, a fuzzy controller was used, which had higher results than a PI controller. The mamdani fuzzy inference system with two inputs and a single output was utilized.

The input power for 5-Hp induction motor with three strategies: FOC with PI speed control; FOC with GA optimization; FOC with GA and Fuzzy speed controller (FG) were investigated. As it was seen from the results, the input power in FG mode had the lowest value. This means that with a lower input power, the torque of input reference load has been supplied. When the load torque varies between 1 and 20 Nm, the input power using FG algorithm was reduced up to approximately 30%. On the other hand, the amount of loss with FG method had significant advantages than two other different torques.
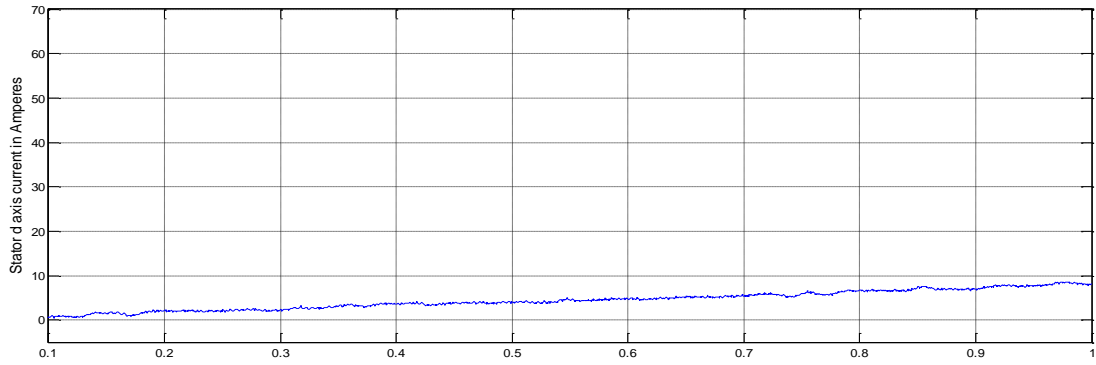

Fig. 9.   Motor torque (TL= 0 to 20 Nm)

Fig. 10. Current of the stator d axis (TL=0 to 20 Nm)
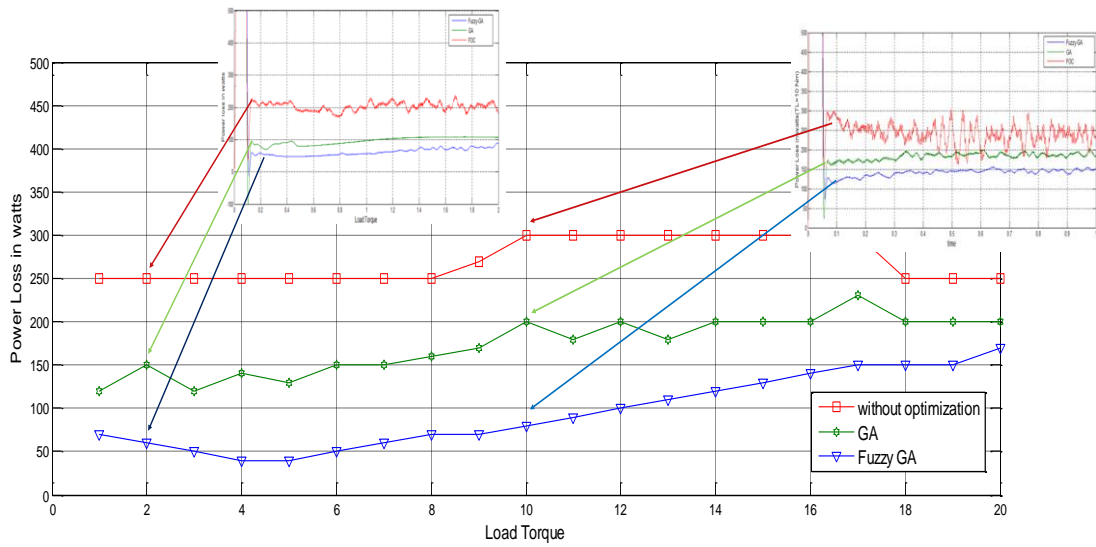

Fig. 11. Loss against load variation 1-20 Nm (wr=100rad/s)
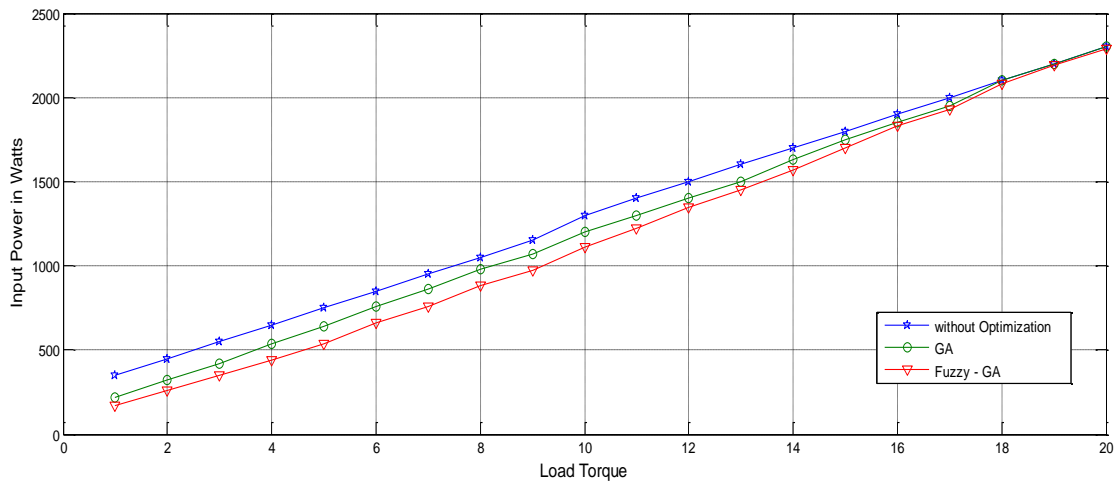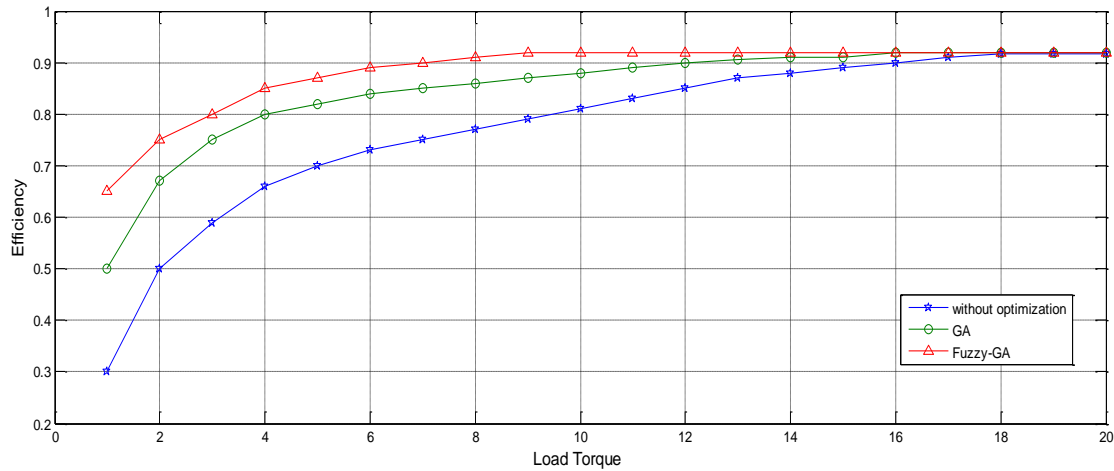

Fig. 12. Amount of input power consumption against load variation 1 - 20 Nm(wr=100 rad/s)

Fig. 13. Efficiencyagainst load variation1 - 20 Nm(wr=100 rad/s)

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Appendix1
Motor parameters

Motor 5 hp , 1750 rpm , 460 v	
rotor resistance =1.083	Stator resistance =1.115
rotor inductance =0.0059	stator inductance =0.0059
Inertia = 0.02	Mutual inductance= 0.2037
friction factor= 0.005752	pole pairs = 2

Appendix2

Output power,imr,power loss,input power and Efficiency with fuzzy-Ga approach

Load Torque (Nm)	Out put Power (w)	Ref Imr(A) GA	Power Loss(w) FOC	Power Loss(w) GA	Power Loss(w) FG	Input Power(w) FOC	Input Power(w) GA	Input Power(w) FG	Efficiency FOC	Efficiency GA	Efficiency FG
1	100	1.6	250	120	70	350	220	170	0.28	0.45	0.58
2	200	2.3	250	150	60	450	350	260	0.44	0.57	0.76
3	300	2.9	250	120	50	550	420	350	0.54	0.714	0.85
4	400	3.28	250	140	40	650	540	440	0.61	0.74	0.90
5	500	3.64	250	130	40	750	630	540	0.66	0.79	0.92
15	1500	6.9	300	200	130	1800	1700	1630	0.83	0.88	0.92
16	1600	6.95	300	200	140	1900	1800	1740	0.84	0.88	0.92
17	1700	7	300	230	150	2000	1930	1850	0.85	0.89	0.92
18	1800	7.15	250	200	150	2050	2000	1950	0.87	0.90	0.92
19	1900	7.35	250	200	150	2150	2100	2050	0.89	0.90	0.92
20	2000	7.50	250	200	170	2250	2200	2170	0.89	0.90	0.92