

Comparison Between PSO and Genetic Algorithms and for Optimizing of Permanent Magnet Synchronous Generator (PMSG) Machine Design

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Abstract

This paper proposes application of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) in the design of direct-driven permanent magnet synchronous generator machine (PMSGs) for wind turbine applications. The power rating of these machines is in the mega watt (MW) level. The constraints and requirements of the generator are outlined. The proposed design scheme optimizes various PMSG parameters like Pole pair number, Linear current density, Air gap thickness, Rotor outer diameter, Relative width of the permanent magnet etc to achieve certain objectives like maximizing efficiency, increasing Torque, improving power factor etc. The results obtained by GA algorithm and those by PSO algorithm are compared. The performance of Particle Swarm Optimization is found to be better than the Genetic Algorithm, as the PSO carries out global search and local searches simultaneously, whereas the Genetic Algorithm concentrates mainly on the global search. Results show that the proposed PSO optimization algorithm is easy to develop and apply and produced competitive designs compared to the GA algorithm.

Keywords: Particle swarm optimization; Genetic Algorithm; permanent magnet synchronous generators; wind turbine; kinetic energy

1. Introduction

Wind energy is the most fast growing renewable energy source in the world. The Kinetic energy of wind is converted into mechanical power by using the wind turbine. Afterwards, mechanical power is then converted into electrical power by a generator which is coupled to the wind turbine. In general, there two types of wind turbines: vertical-axis and horizontal-axis wind turbines. A horizontal-axis is widely used WT (wind turbine) in that, rotating blades are situated on parallel-axis to the land. The gearbox is employed in Wind Turbine (WT) machine for transferring power from rotating wind turbine blades to generator. The types of drive train concepts used are Single-Stage (1G), Multi-Stage (3G) and Direct-drive (DD). Single-Stage [1] normally having a stage of planetary and with the varying gears number which depends upon power rating. It is having some more number of bearing and gears compare with the multi-stage, which help to increase the machine reliability. The multi-stage WT generally consists of parallel-shaft-helical stage gear and planetary stage gear [2] so that multi-stage WT has more speed than single-stage.

Direct-drive, due to the omission of gearbox from drive train [3] has minimal maintenance cost, higher speed and reliability. The pole pair's number is doubled up to decrease the demagnetization risk of magnets, reduce the end winding and yoke dimensions. Increasing the pole-pair's number does not increase the excitation losses (as in the synchronous generator) because of the permanent magnets are castoff [4].

The several types of algorithms that have been proposed previously are: Bees Algorithm is swarm intelligence based optimization algorithm which was proposed by Pham et al [5] in 2005, a bees' algorithm has capability to perform long task in multiple directions that guarantees developing some larger areas/patches [6,7].

Evolutionary Algorithms (EAs) are stimulated from the recombination, mutation and natural selection of the [8] biological mechanism. Low rate of convergence and dependence upon mutation and recombination rates causes the weakness on local search and encoding scheme.

Space layout problems can be solved through the application of Genetic Algorithm (GA) and Hybrid Genetic Algorithm (HGA) as proposed by Jyoti Sharma et. Al [9]. These type of algorithms become more suitable when the problem size is varied and when the problem is clearly defined. With larger data, designing becomes very problematic thus, we require good computer in designing ability. Like fuzzy system and Neural Network (NN) techniques GA is soft technique of computing that can be used to empower the computer with the capability of human thinking.

Developing functions is the other goal that will result in very efficient optimization of parameters used for motor designing. To achieve the better optimization outcomes here we have applied the method of particle swarm optimization (PSO). PSO uses the communal behavior of population groups in the environment like fish schooling 'or' flocking of bird 'or' animal herds etc.

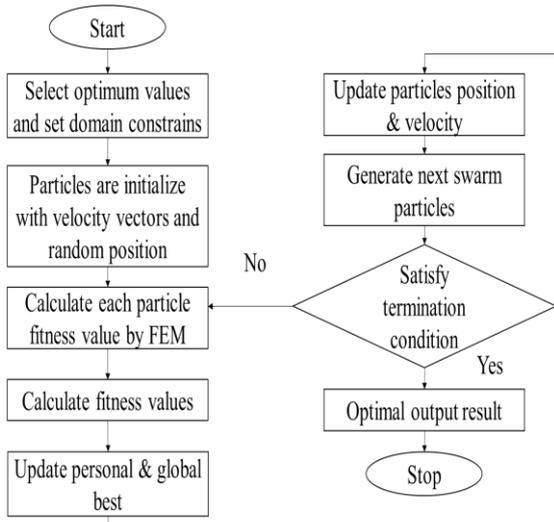


Fig. 1: Optimization design flow-chart using PSO-FEM

Its consists of population called as swarm and, every member of swarm is called as a particle [10]. The particle used to search the global optimum with a set velocity, due to the particle upgrade and, update its position as per its neighborhood and itself. Kennedy et. A [11] proposed PSO having capability to do both global and local searches efficiently and which can be implemented easily and has fewer parameters for the tuning. The optimization design flow chart by PSO-FEM is shown in the Figure I.1. In this way, an optimization of wind turbine generator design can be achieved.

2. Literature Survey

James Carroll et al. [12] has described the drive train performance and configurations of various sites has illustrated through the distance to coast. The requirements of repair resources to a maintenance model, operation and, accessibility of offshore to calculating the maintenance costs, operation and, availability for the standard wind-farm that consist 100 number of turbines. The predicted outcomes that wind turbines with PMG (permanent magnet generator) and, highly valued power-converter will be a lower operation and higher availability compare with DFIG (doubly fed induction generators). It has also to improve the detailed analysis of offshore failure rate for direct-drive turbines and for two-stage configuration of gearbox along with more restoration-time analysis.

2.1. Nomenclature used in modelling

ω	Efficiency
P_{fac}	Power factor
E_{pow}	Electrical power
M_{pow}	Mechanical power
D_A	Linear current density
D_j	Current density
P_{volt}	Phase voltage
B_{emf}	Back induced electromotive force
P_A	Apparent power
n	Pole pair number
s	Speed
f_q	Frequency
D_{or}	Rotor outer diameter
l_m	Effective machine length
D_{Ag}	Air-gap diameter
γ	Air-gap
P_p	Number of slots-per-pole-per-phase
N_p	Number of phase
q	Number of slots
ρ_p	Pole pitch
S_{OD}	Relative stator-outer diameter

τ_1	Fundamental torque
τ	Torque density
τ_{rel}	Reluctance torque
I_d	Inductance
$\sin \theta_a$	Load Angle
N	Power

2.2 Design Procedure

Initial parameters

Normally, some initial conditions are necessary to design an electrical machine. The machine is future describes the necessities about speed, shaft power and supply voltage. Initially, estimation of power factor and efficiency are chosen. The value for the desirable electrical power E_{pow} is calculated using estimated efficiency ω .

$$E_{pow} = \frac{M_{pow}}{\omega} \quad (1)$$

where, the M_{pow} is mechanical power. The D_A is linear current density. The mechanical power can be calculated as:

$$M_{pow} = \omega P_{fac} \frac{P_{volt}}{B_{emf}} P_A \quad (2)$$

where, the P_{volt} is phase voltage, B_{emf} is Back EMF, and P_A is Apparent power.

n is pole pair number that depends upon the frequency f_q and on the turbine speeds.

$$n = \frac{f_q}{s} \quad (3)$$

Frequency converter supplies a mechanism, which commonly in case of Permanent Magnet Machine, the properties of machine can be affects through incorrect number of poles.

Mechanical dimensions

The important dimensions are outer diameter of the stator and machine actual length, due to these, the machine sizes is determined. If these values are larger, then heavier will be the mass of machine and the machine volume becomes larger. The rotor outer diameter D_{or} given by:

$$D_{or} = \frac{l_m}{D_{Ag}} \quad (4)$$

where, Air-gap diameter is D_{Ag} and effective length of machine is l_m . The air gap γ of Permanent Magnet Machine (PMM) can found by equation given below.

$$\gamma = \frac{0.2+0.01N^{0.4}}{1000} m, \quad n = 1 \quad (5)$$

$$\gamma = \frac{0.18+0.006N^{0.4}}{1000} m, \quad n > 1 \quad (6)$$

Torque density, output power, efficiency and density

The torque (τ_1) of wind turbine generator can be evaluated by given equation 7, where f_a denotes the angular frequency, inductance is given by I_d and load angle is $\sin \theta_a$.

$$\tau_1 = \frac{N_p \cdot P_{volt} B_{emf}}{2\pi\omega \cdot f_a I_d} \sin \theta_a \quad (7)$$

The machine torque consists of the torque of reluctance τ_{rel} and τ_1 fundamental torque

$$\tau = \tau_1 + \tau_{rel} \quad (8)$$

If the reluctance torque $\tau_{rel} = 0$ and, the torque to be $\tau = \tau_1$. This is the case with surface magnet-machine.

Here, the M_{pow} is Mechanical Power. For the motor, M_{pow} is the output power where, Z_s denotes power losses. $M_{pow} + Z_s = E_{pow}$ Here, M_{pow} and Z_s is used to calculate electric power, and the efficiency ω can be calculated by;

$$\omega = \frac{M_{pow}}{M_{pow} + Z_s} \quad (9)$$

The (D_j) maximal current density given as,

$$D_j = \frac{I_n / n_p}{A_{con} P_{cond}} \quad (10)$$

where, parallel number of path n_p , Parallel conductor number in one slot is P_{cond} and A_{con} is conductor area.

The (D_A) density of linear current is

$$D_A = \frac{N_p C_{ph} A_s}{\pi r_s} \quad (11)$$

Here, N_p is parallel number of paths, stator inner radius r_s , C_{ph} coils number turns in phase and A_s is stator current.

3. Results

The PSO algorithm information sharing mechanism is expressively different from ‘Genetic Algorithm’. In PSO, genetic operation is not present such as mutation and crossover, in this particle with internal velocity can update themselves. Moreover, it has memory that is the important factor to the algorithm. Here, we have taken the 10 best cases for both Genetic and PSO (Particle Swarm Optimization) algorithm. In PSO, 10 iteration has been taken and for each iteration it generates the 100 particle, in which it check for best values and take only that values for displaying. In genetic algorithm, it firstly generates the particle and then GA go for iteration to find best value for each case. Both algorithms are capable to generate new optimized solution in the two parent’s neighborhood through crossover in ‘GA’ and, through best position attraction in PSO. There are total ten number of objectives are evaluated with using of both Genetic and PSO algorithm, the objectives are power output, torque density, efficiency, power factor, cost, electric power, power loss, torque, and, maximal and linear current density. To optimize the wind turbine generator system for the maximum efficiency, fourteen variables are selected to vary within a specific range, including the pole pair number, desired linear current density, desired current density, Air gap thickness, Rotor

outer diameter, Relative magnet width, Tangential stress, Rotor Yoke flux density, Number of slots per pole, Relative stator outer diameter, Relative slot opening, Relative slot width, Relative slot height (h1) and Relative slot height (h2). The peak flux density in the rotor yoke is set to 1.6T to minimize the mmf drop in the yoke of the rotor. The current density in the stator windings is limited to 2-6A/mm² and the current loading is limited to 35-65kA/m to prevent excessive cooling requirements.

The maximum flux density in the stator and rotor yoke is set to 1.2T, in order to reduce the drop in mmf in those parts. To optimize each wind turbine generator system for the minimum generator system cost (16), six variables are selected to vary within a specific range, including radius of the air gap (r_s), the stator length (L), the slot height (h_s), the pole pitch (p_p), the peak air gap flux density (B_g) and the peak stator yoke flux density (B_{ys}).

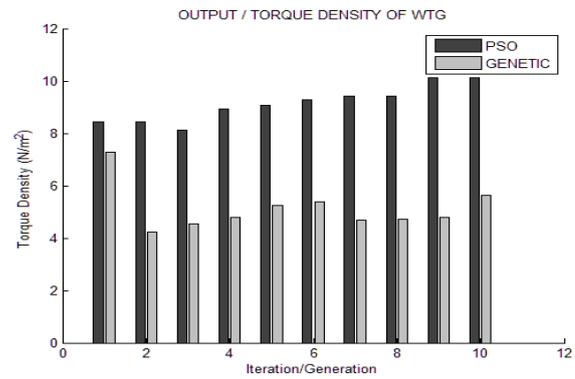


Fig. 1: Torque Density of Wind Machine

Torque density of wind machine shown in figure.1 where, torque density of using both PSO and Genetic are compared and it seems to be for each case torque density are higher in using of PSO algorithm as compared to genetic algorithm. The PSO output of torque density is shown by dark grey color and light grey represents the Genetic output of Torque density.

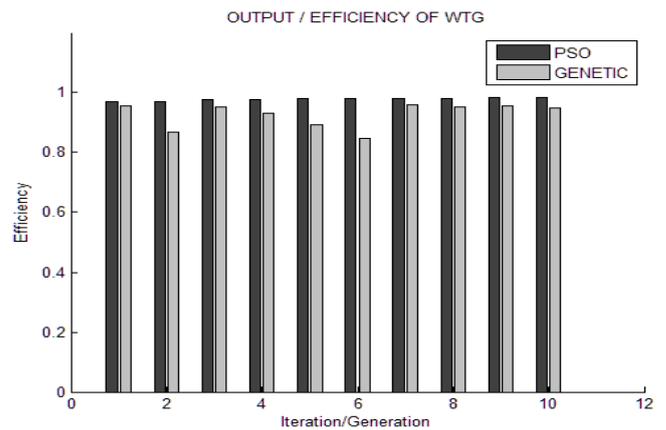


Fig. 2: Efficiency of Wind Machine

Table 1: Wind Machine Efficiency

Efficiency of wind machine	
(GA)	(PSO)
0.954453	0.970352
0.867962	0.970352
0.952731	0.975591
0.932105	0.976992
0.891318	0.980610
0.845964	0.981141

0.961099	0.981975
0.951653	0.981975
0.957691	0.982524
0.948921	0.982524

Efficiency of wind machine from both PSO and Genetic, for 10 best cases is as shown in the table1. The best efficiency found for genetic is 96.1099% in seventh case and, PSO best efficiency found as 98.2524% in 9th and 10th case. In figure 2 describes all the variation in efficiency of each best cases.

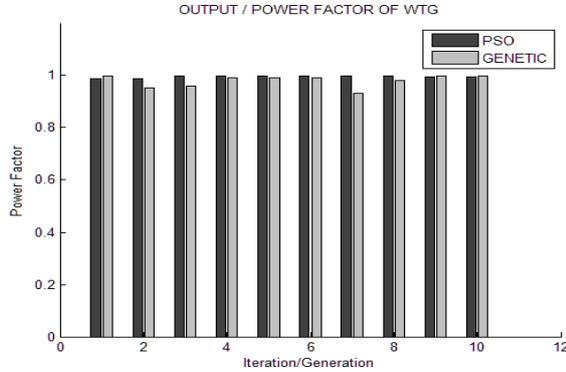


Fig. 3: Power Factor of WTG

The **Power Factor (PF)** of an electrical power system (machine) described as the 'ratio' of real power that flowing to load in the circuit apparent power. As per shown in figure 3 the power factor for both Genetic and PSO are almost same.

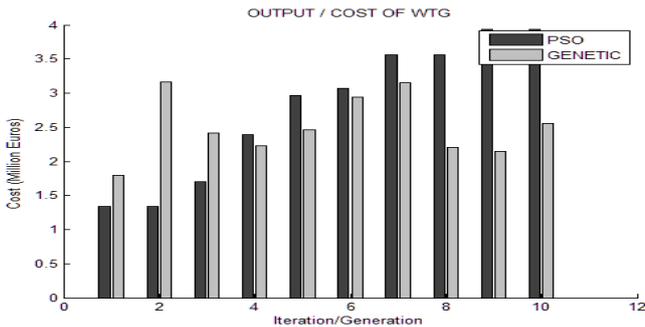


Fig. 4: Wind machine cost

Table 2: Wind Machine Cost

Cost of wind machine (€)	
(GA)	(PSO)
1790090	1338930
3164438	1338930
2413178	1700465
2228837	2397062
2460321	2970399
2939605	3070461
3150552	3562061
2210490	3562061
2151480	3941506
2553505	3941506

Table 2 defines the cost of wind machine for every case and there is significant difference between Genetic and PSO wind machine cost. The graphical representation of wind machine cost displayed in figure 5.

The maximum cost found for PSO is 3941506 € in 9th and 10th case whereas the corresponding efficiency for these cases using PSO is 98.25% which is maximum. This analysis shows that a more efficient generator may be an interesting solution even if it is more expensive. The return of investment (ROI) for the generator designed using PSO would be much higher because of its higher efficiency and lower losses. Furthermore, a more efficient machine operates with a less elevated temperature, which means that this machine is more durable and less susceptible to faults.

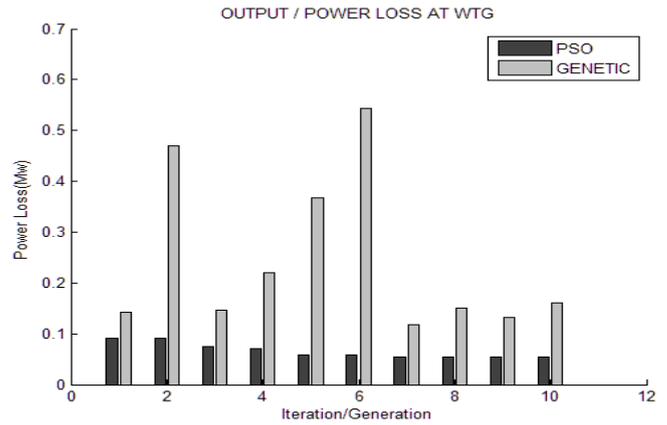


Fig. 5: Power Loss in Wind machine

Table 1: Wind Machine Power loss

Power Loss		
(GA)	(PSO)	
143229.8	92078.28	92078.28
470270.4	92078.28	92078.28
146166.1	75148.77	75148.77
219029.2	70875.60	70875.60
366859.6	59353.31	59353.31
544409.1	57721.45	57721.45
118542.1	55156.84	55156.84
151096.9	55156.84	55156.84
132241.6	53608.63	53608.63
160948.7	53608.63	53608.63

Power loss in wind turbine displayed in figure 5 and in table 1 where, the huge loss of power (in MW) in genetic and the power loss is decreasing for each case of PSO WTG.

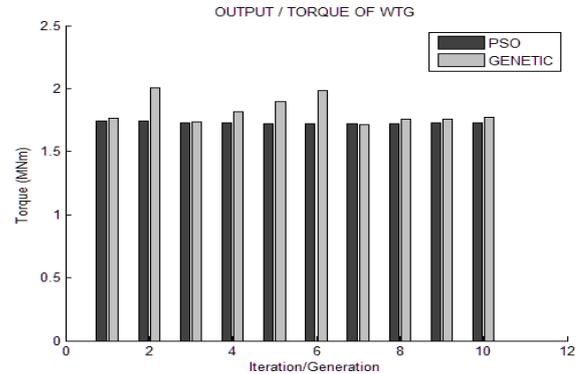


Fig. 6: Torque of Wind Turbine Generator

4. Conclusion

In this paper, a comparison of two Evolutionary Algorithms (EA): Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for optimal design of Permanent Magnet Synchronous Generator (PMSG) machine is made. Comparisons between the results obtained by GA method and those by improved PSO method are made. The experimental results show that the PSO method can locate the optimal or near optimal parameter in the solution space and thereby able to achieve a better quality solution than the GA algorithm. It is easy to program in PSO method and manipulate to suit the requirements of this PMSG design. The PSO optimization method was successful in producing a machine with highest efficiency and maximum torque density compared to that designed using GA method. PSO and GA are compared in this paper with the aim of finding which algorithm is more suitable for machine design optimization. The results obtained show that PSO and GA both have the ability to find the correct optimal solution, but PSO has a better performance in finding the global optima. Furthermore, in terms of the computational efficiency, which is a key requirement for the algorithms in machine design, PSO outperforms GA significantly. PSO has a lower performance degrading with a

smaller population size, and higher robustness to its running coefficients. The comparison results indicate that PSO should be preferred over GA particularly when computational time is a limiting factor.

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