International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 11 (2015) pp. 29569-29579

http://www.ripublication.com

A Novel Design Optimization of a Fault-Tolerant AC Permanent Magnet Synchronous Machine-Drive System

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Abstract

This paper investigates an optimization procedure for the design of a permanent magnet synchronous generator using a particle swarm optimization (PSO) and Harmony search (HS). The PSO is proposed to minimize the cost reduction and to maximize the efficiency of the constraints level. The proposed procedure has two stages for motor design. In the first stage, the stator parameters are optimized while in the second stage, the field and maximum flux density are designed. The proposed algorithm is efficiently compared with the practical experience-based method. The proposed procedure is efficiently design the PMSG based on the 4- pole proto-type synchronous machine which is produced at 27 military production factories. The proposed procedure leads to more economical motor compared to the practical experience based method. Also, the proposed procedure maximizes the SG developed apparent power and reduces the field windings in terms of their conductors' diameters and number of conductor per slot..

Keywords: Permanent magnet synchronous generator(PMSG),Particle swarm optimization(PSO), Harmony search(HS),Optimization methods

Introduction

Permanent magnet synchronous motors are frequently used in industrial applications. Especially their compact design, high efficiency, high power/weight and torque/inertia ratios can be shown as the most important advantages of PMSGs. On the other hand, the high cost and their time-varying magnetic characteristics are the disadvantages of PMSGs. However, the performance is sensitive to the variation of motor parameters, especially the rotor time-constant, and the saturation of the magnetizing inductance. Recently, much attention has been given to the possibility of identifying the changes in motor parameters of PMSG while the drive is in normal operation. This stimulated a significant research activity to develop PMSG vector control algorithms using nonlinear control theory in order to improve performances, achieving speed and torque tracking. All this, usually require shaft mounted sensors for variable speed applications.

However, these mechanical sensors will increase the complexity and lower the reliability of the drive system. In recent years, mechanical sensorless drives have received a wide attention. The basic idea for sensorless drive is to estimate motor speed and position through measured stator terminal quantities. Traditional methods of detecting induced electromotive forces or calculating the stator flux linkage may work well under some operating conditions The electrical machinery is complicated by using the large number of complex material parameter and geometries. The large number of conflicting design objectives which are faced by the designer can also lead the complications of the system. Important design objectives, initially system structure are performed in analytical and magnetic circuit model equivalent. Synchronous motors are being increasingly used in different industry sectors in new applications or as alternatives to induction motors in current applications. This is due to their many advantages including high efficiency, compactness, fast dynamics and high torque to inertia ratio. Synchronous motors with extra features of mechanical robustness, capability of flux weakening and high speed operation are particularly suitable as variable speed drives. The realization of these merits depends greatly on motor configuration.

Therefore, a great deal of attention has been focused on the optimal design of synchronous motors in recent years. In the literature, different optimization procedures were carried with different objectives, depending on the prospective application of the motor and the user's desire. Comparative studies of minimization techniques for optimization of ac machines design was presented with greet progress in mathematical tools leads to use these optimization tools for the electric machines design in reference. The optimization procedures are applied for IM . The practical consideration was presented for the IM design. The SG optimal design using Immune design problem in considered the torque capability and low magnetic volume while in a multi-objective optimal design procedure for the interior permanent SM with improved core formula was presented. The project is to investigate and develop permanent magnet synchronous motors for traction applications such as electric driven for lifts. An existing induction (asynchronous) traction motor that can be found in electric forklifts is used as benchmark for the study.

The aim of the design is to have a high efficient permanent magnet motor drive that could be a feasible alternative to the induction motor drive in a longer perspective, despite a higher initial cost due to the expensive rare-earth permanent magnet (PM) materials that are preferably used in these types of motors.These type of permanent magnet synchronous motors to achieve high torque development capability with low permanent magnet consumption. A multi-objective optimization is performed in search for optimum magnet dimensions and location. The design optimization results in a motor structure superior to original motor specifications. For reasons, experience based design methods cannot find Optimal design solutions when dealing with nonlinear systems. Also, these methods do not guarantee a global solution for nonlinear systems; stochastic search algorithms may provide a promising alternative to these traditional approaches.

Previous Research

Numerous related research works are already existed in literature which based on optimization of PMSG machine circuit. Some of them are reviewed here.

Divya P*et al* [6],presented the design optimization methods described is a computationally-efficient FEA technique. For the purpose of analysis minimum number of magneto static are used and it makes possible for the study of the many candidate motor designs with typical PC workstation computational resources. A multi-objective differential evolution algorithm that considers a large number of independent stator and rotor geometric variables and performance criteria, to develop software that efficiently optimizes the design of various types of machines using finite element (FE) analysis in a high throughput computing environment to achieve the best possible performance results in the least amount of computational time.

Kendouci Khadija*et al*[7],presented a simple and robust speed control scheme of Permanent Magnet Synchronous Motor (PMSM). It is to achieve accurate control performance in the presence of load torque and plant parameter variation. A Kalman filter is used to estimate the rotor speed. A nonlinear back stepping control which is based on both feedback laws and Lyapunov theory is easily implemented on a PMSG driver using a TMS1103 DSP. The effectiveness of the proposed robust speed control approach is demonstrated by simulation and experimental results instructions.

R. A. El-Sehiemy,*et al*[8],investigates an optimization procedure for the design of a synchronous motor (SM) using a particle swarm optimization (PSO) procedure. The PSO is proposed to minimize motor volume and to maximize the motor output power. The proposed procedure has two stages for motor design. In the first stage, the stator parameters are optimized while in the second stage, the field and damper winding are designed. The proposed algorithm is efficiently compared with the practical experience-based method. The proposed procedure is efficiently design the SM based on the 4- pole proto-type synchronous machine which is produced at 27 military production factories. The proposed procedure leads to more economical motor compared to the practical experience based method.

Martin Hafner *et al*[9],has presented an optimal power management mechanism for paper is to consider thermal analysis as part of an automated sizing and design process. The temperature estimation at characteristic points of the machine, and in particular in permanent magnets, is essential to accurately simulate the electromagnetic behavior and avoid irreversible demagnetization. In this paper, an electromagnetic dimensioning model, parameterized by finite element analysis, is coupled to a thermal lumped-parameter model to constitute a fast and efficient design tool for electrical machines.

Adel El Shahat *et al* [10], presented a dynamic modeling simulation for ac Surface Permanent Magnet Synchronous Motor (SPMSM) with the of MATLAB – Simulink environment. The proposed model would be used in many applications such as automotive, mechatronics, green energy applications, and machine drives. The modeling procedures are described and simulation results are presented. The validity of this dynamic model here is verified. Then, two genetic algorithm trials are presented to improve SPMSM performance. Maximum torque per ampere genetic algorithm function with maximum efficiency constrained is illustrated. Also, genetic algorithm maximum efficiency function constrained by GA maximum power factor is proposed. Simulations are implemented using MATLAB with its genetic algorithm toolbox. Finally, the required voltage to drive the motor at the desired improved characteristics is deduced for each case. All various characteristics are well depicted in the form of comparisons with such ones from original characteristics at rated voltage.

Alexandru*et al* [11],presented a hybrid soft computing approach for optimizing the performance of electrical drives where many degrees of freedom are allowed in the variation of design parameters. The hybrid nature of our approach originates from the application of multi-objective evolutionary algorithms (MOEAs) to solve the complex optimization problems combined with the integration of non-linear map-pings between design and target parameters. These mappings are based on artificial neural networks and they are used for the evaluation of individuals (design parameter vectors). The mappings substitute very time-intensive element simulations during a large part of the optimization run.

The main disadvantages of the above references are that the complexity in the design and cost. To overcome the drawbacks we propose a new optimization model and simulation of a PMSG is proposed. Modeling and simulation are implemented using MATLAB/SIMULINK and Sim Power Systems software packages to verify the effectiveness of the proposed system.

Proposed Approach

It has been efficiently solved the problem of synchronous generator design using a particle swarm optimization ,optimization function and constraints technique. The results obtained with the Designed procedures are compared with experience-based method. The proposed PSO technique offers some advantages over deterministic methods .Its maximizing the power compared to the conventional design method. The total ampere conductor using the proposed optimization technique is saved .The increased maximum flux density voltage leads to more reduction in damper winding diameter. While, The increased field voltage leads to more reduction in the field conductor per slot. This project addresses new simple dynamic PMSG modeling to can be used in many topics like in automotive applications, mechatronics, green energy applications, machine drives, etc.

This dynamic model is developed by coupling electrical equations and mechanical equations of the PMSG. Also, there are two proposed trials for performance improvement of PM synchronous Generator. This idea is done by implementing two genetic algorithm functions with different constraints, same optimizing variable bounds and the same optimizing variable which is the voltage. The last one about maximum efficiency constrained by maximum power factor has the most powerful effect on all various machine characteristics. Second rank for performance improvement is in maximum flux density per ampere with maximum efficiency constrained. All functions and simulations are implemented using Matlab environment with the aid of Particle Swarm Optimization techniques.

Modelling of PMSG

In order of optimization modeling of the PMSG for Turbine application is integrated with wind speed profile, wind turbine and diode rectifier. In PMSG, the excitation is provided by permanent magnets instead of field winding. Permanent magnet machines are characterized as having large air gaps, which reduce flux linkage even in machines with multi magnetic poles.

The low rotational speed generators can be manufactured with relatively small sizes with respect to its power rating. Moreover, gearbox can be omitted due to low rotational speed in PMSG wind generation system, resulting in low cost. In a recent survey, gearbox is found to be the most critical component, since its downtime per failure is high in comparison to other components in the wind turbine system.

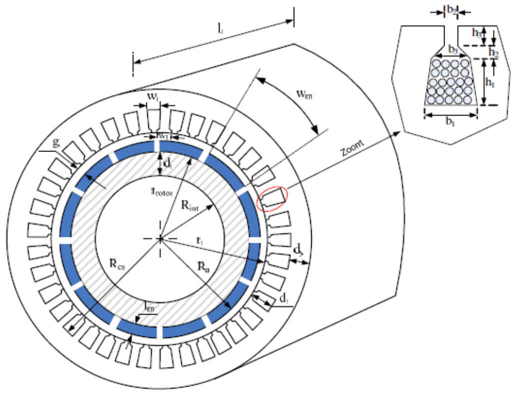

Figure 1: PMSG Topology

A. Modeling of the PMSG

A synchronously rotating d-q reference frame has been selected to model the dynamic behavior of the PMSG, considering the generator convention, the stator and rotor voltages are given by the following equations

$$v_{ds}= -R_s i_{ds} - \omega_s \lambda_{qs} + \frac{d\lambda}{dt}_{ds} \quad (1)$$

$$v_{qs} = -R_s i_{qs} + \omega_s \lambda_{ds} + \frac{d\lambda}{dt}_{qs} \quad (2)$$

$$v_{dr} = R_r I_{dr} - (\omega_s - \omega_r)\lambda_{qr} + \frac{d\lambda}{dt}_{dr} \quad (3)$$

$$v_{qr} = R_r i_{qr} + (\omega_s - \omega_r)\lambda_{dr} + \frac{d\lambda}{dt}_{qr} \quad (4)$$

The indices d and q indicate the direct and quadrature axis components of the reference frame.

The flux linkage in (1) and (4) is defined as

$$\lambda_{ds} = -L_s\, i_{ds} + L_m\, i_{dr} \quad (5)$$

$$\lambda_{qs} = -L_s\, i_{qs} + L_m\, i_{qr} \quad (6)$$

$$\lambda_{dr} = L_r\, i_{dr} + L_m\, i_{ds} \quad (7)$$

$$\lambda_{qr} = L_r\, i_{qr} + L_m\, i_{qs} \quad (8)$$

This model depends on geometrical characteristics and electromagnetic characteristics, the 8 basic design variables for the sizing PMSG model is presented on Table I. The electromagnetic and geometrical parameters of PMSG should calculate from these 8 basic variables.

The geometrical characteristics of PMSG are illustrated on Fig. 1. With this topology, we have to define the 8 geometrical fundamental dimensions on Table I.

Table 1: Geometrical and Basic Design Parameters

PMSG Geometrical parameters		PMSG basic design variables	
r_s	Bore radius	R_{rl}	Bore radius/length ratio
g	Air gap	R_{dr}	Slot depth/ bore radius ratio
l_r	Length active	J_s	Current density
d_s	Slot depth	B_y	Yoke induction
w_s	Slot width	P_b	Power at the base functional point
w_T	Tooth width	p	Number of pole pair
d_r	Rotor yoke thickness	N_{spp}	Number of slots per pole and phase
d_y	Stator yoke thickness	Ω_b	Base speed

Optimal Design Search Algorithm

A) Harmony Search Algorithm

Harmony search (HS) is a music-inspired algorithm and has been applied to various optimization problems including music composition, Sudoku puzzle, magic square, timetabling, tour planning, logistics, web page clustering, text summarization, Internet routing, visual tracking, robotics, energy system dispatch, power system design, cell phone networking, structural design, water network design, dam scheduling, flood model calibration, groundwater management, soil stability analysis, ecological conservation, vehicle routing, heat exchanger design, satellite heat pipe design, offshore structure mooring, RNA structure prediction, medical imaging, medical physics. Each musician in music performance plays a musical note at a time, and those musical notes together make a harmony. Likewise, each variable in optimization has a value at a time, and those values together make a solution vector. Just like the music group improves their harmonies practice by practice, the algorithm improves its solution vectors iteration by iteration.

Psudocode for HS algorithm
begin
*Objective function f(**x**), **x**=(x1,x2, …,xd)T*
Generate initial harmonics (real number arrays)
Define pitch adjusting rate (rpa), pitch limits and bandwidth
Define harmony memory accepting rate (raccept)
***while** (t<Max number of iterations)*
Generate new harmonics by accepting best harmonics
Adjust pitch to get new harmonics (solutions)
***if** (rand>raccept), choose an existing harmonic randomly*
***else if** (rand>rpa), adjust the pitch randomly within limits*
***else** generate new harmonics via randomization*
end if
Accept the new harmonics (solutions) if better
end while
Find the current best solutions
end

The HS algorithm basically has three operations, such as memory consideration, pitch adjustment, and random selection. Using memory consideration operation, HS chooses a value from harmony memory (HM); using pitch adjustment operation, HS chooses a value which is slightly modified from HM; and using random selection operation, HS chooses a value randomly from entire value range. These basic operations constitute a novel stochastic derivative, instead of traditional calculus-based derivative, in order to search for the right direction to the optimal solution.

B) Particle Swarm Optimization

Particle swarm optimization is a heuristic global optimization method and also an optimization algorithm, which is based on swarm intelligence. It comes from the research on the bird and fish flock movement behavior. The algorithm is widely used and rapidly developed for its easy implementation and few particles required to be tuned. Particle swam optimization is a new heuristic optimization method based on swarm intelligence. Compared with the other algorithms, the method is very simple, easily completed and it needs fewer parameters, which made it fully Developed.

The motion of the particles has two major components: a stochastic component and a deterministic componentin terms of velocity and position vectors (solution vectors)

$$v_i^{t+1} = v_i^t + \alpha\, \varepsilon_1 (x_i - g^*) + \beta\, \varepsilon_2 (x_i - x_i^*), \qquad x_i^{t+1} = x_i^t + v_i^t,$$

where *vi t* and *xit* are the velocity and position of particle *i* at time *t*, respectively. ȝ 1 and ȝ 2 are two random vectors, while a and b are constants

Due to its many advantages including its simplicity and easy implementation, the algorithm can be used widely in the fields such as function optimization, the model classification, machine study, neutral network training, the signal procession, vague system control, and automatic adaptation control. Because they are transmitting the information, especially the good information at any time while searching the food from one place to another, conducted by the good information, the birds will eventually flock to the place where food can be found. As far as particle swam optimization algorithm is concerned, solution swam is compared to the bird swarm, the birds' moving from one place to another isequal to the development of the solution swarm, good information is equal to the most optimist solution, and the food resource is equal to the most optimist solution during the whole course.

Flowchart

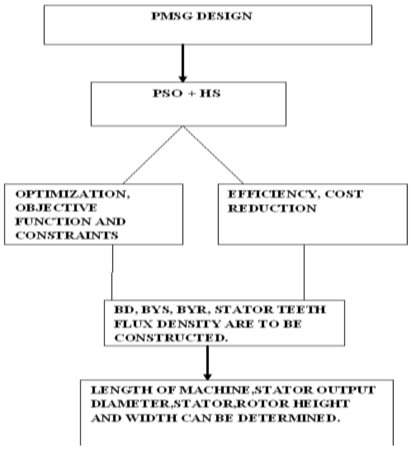

Figure 2: Flowchart of Proposed System

Simulation Results and Discussions

The PSO particles for the proposed PMSG model with respect to number of iteration is given in the following figure. The output characteristics of the PSOOptimization model are shown in following simulation results.

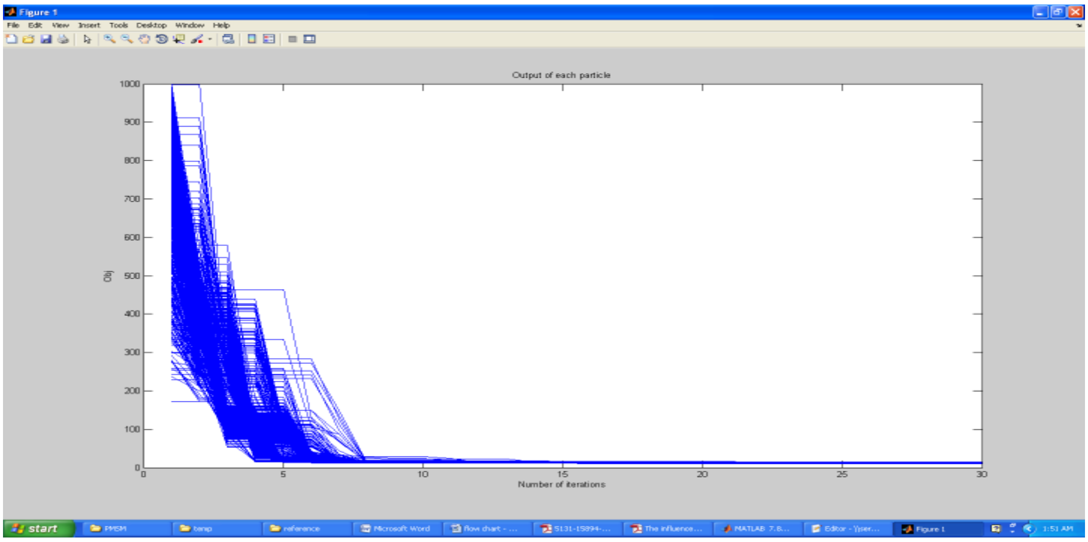

Figure 3: Simulation result for PSO optimization

From the above Simulation result shows that the 1000 input particle with respect to iteration is starting from 0 to 30 number of itertions.

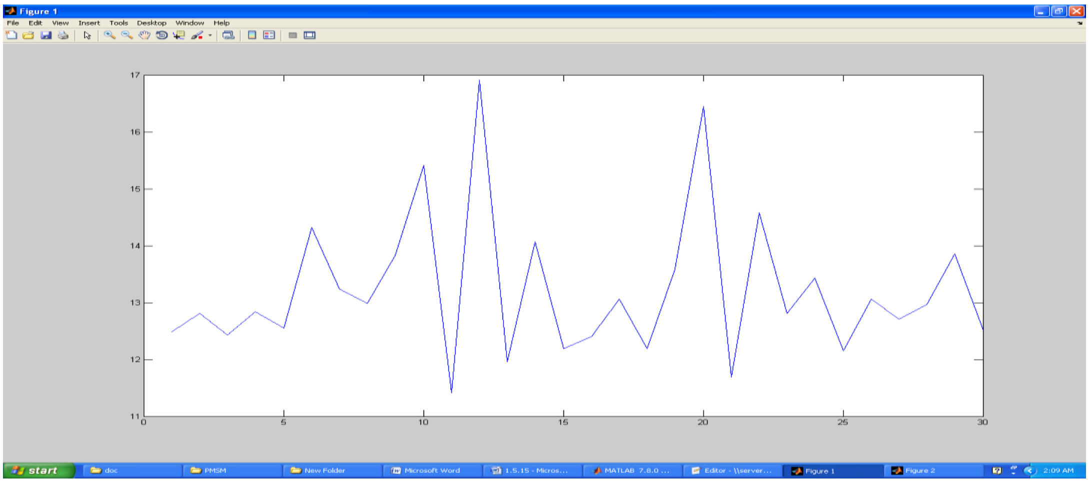

Figure 4: Simulation result for Best results &solution

The above Simulation result shows that the Best results and best solutions of Harmony search algorithm.

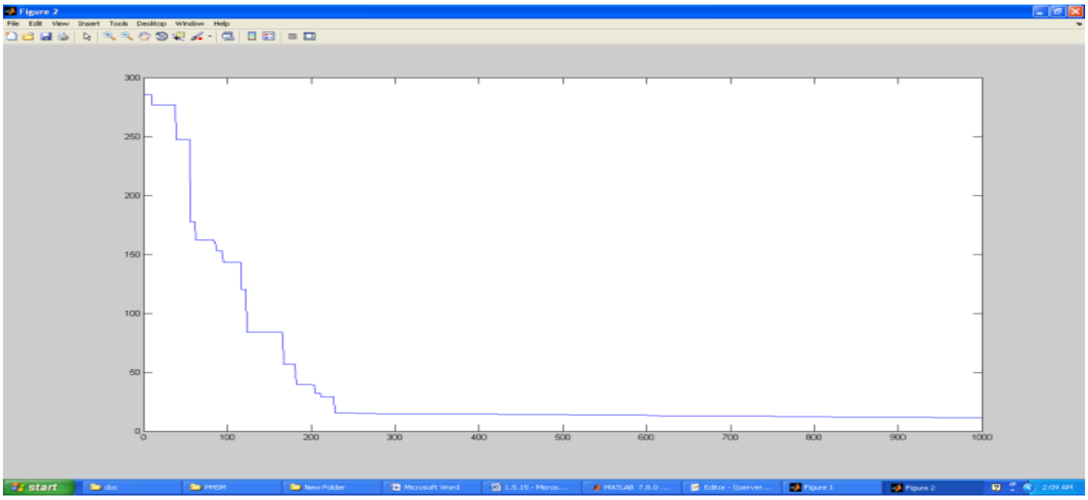

Figure 5: Simulation Result For Characteristics of The Best Solution

From the above Simulation result performances, the optimized output of the proposed HS algorithm are evaluated at different simulation period and different iterations. According to the simulation period variations, the output efficiency of the proposed system is varied.

Conclusion

In this project finally we are going to concluded the optimization ,objective functions and constraints of the permanent magnet synchronous generator has been optimized based on in its power density by applying a set of sizing analytical equations which deal with the main geometrical, electric and mechanical parameters that define the machine. Comparisons with optimized motors data found in the technical literature show the accuracy of the applied approach since similar power densities are achieved in comparison with previous designs, even when applying fault tolerant constraints. As expected the efficiency is increased in a fault tolerant machine mainly due to inductance constraint, because to achieve such high values of inductance an oversized stator is a must, although this could be overcome with an improved system.

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