Proceedings of the Seventh International Conference on Electronics, Communication and Aerospace Technology (ICECA 2023)
IEEE Xplore Part Number : CFP23J88-ART ; ISBN : 979-8-3503-4060-0

2023 7th International Conference on Electronics, Communication and Aerospace Technology (ICECA) | 979-8-3503-4060-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICECA58529.2023.10394839

Torque Optimization of a Synchronous Motor using a Genetic Algorithm

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Abstract-
A synchronous motor belongs to the class of AC motors. It operates at a fixed speed termed as the synchronous speed, which depends on frequency of applied ac, and number of poles in the motor. Synchronous motors exhibit advantages in terms of precise speed regulation, power factor correction, and high efficiency. Some of the drawbacks associated with synchronous motors are high cost and complexity, and limited range of speed. Torque maximization in a synchronous motor has an instrumental role in improving its efficiency and performance. This maximization can be accomplished using various optimization algorithm viz. Pattern Search, Genetic Algorithm, Simulated Annealing etc. The two prime parameters on which the generated electromagnetic torque depends are the mechanical load and the field current. In the present work, the Genetic Algorithm (GA) is used for the maximization of torque. On the basis of available data, an objective function is formulated in terms of mechanical load and the field current. This objective function is minimized using Genetic Algorithm in MATLAB for maximizing the torque.

Keywords- Synchronous motor; Torque; Optimization; Mechanical load; Field current; Genetic Algorithm

I.INTRODUCTION

The major components present in a synchronous motor are stator, rotor, field windings, and a dc source as shown in Fig. 1[16].

The stator is a stationary component of synchronous motor. It includes a laminated core made of magnetic materials of high-grade, e. g. silicon steel, for minimizing eddy current losses. The stator contains slots for accommodating the stator winding containing multiple coils. These coils produce rotating magnetic field when supplied with the 3 phase ac.

The rotor is the rotating component of synchronous motor. It also includes a laminated core. It can have a salient pole or non- salient pole type construction. The rotor windings conduct the field current generating magnetic field which interacts with rotating magnetic field of stator. The field windings are placed on the rotor. DC is supplied to these windings creating the magnetic field in rotor. It aligns with the rotating field of stator developing the synchronous speed of motor. The dc source used in large synchronous motors is also termed as an exciter which is a small dc generator. Smaller synchronous motors include static rectifiers as a dc source.

In case of synchronous motors having permanent magnet rotors, slip rings are not required, but in synchronous motors having wound rotor, slip rings and brushes are used for making connection between the rotor winding and external dc circuit. Synchronous motors have high quality bearings for supporting rotating shaft and minimizing friction losses.

A very important parameter associated with a synchronous motor is its power factor. It is decided by the phase difference between voltage and current taken by the motor. An overexcited motor functions at a leading power factor, an under excited motor functions at lagging power factor, a fully excited motor functions at a unity power factor. Torque generated in a synchronous motor depends on power factor and excitation current. The torque can be regulated my manipulating the excitation current.

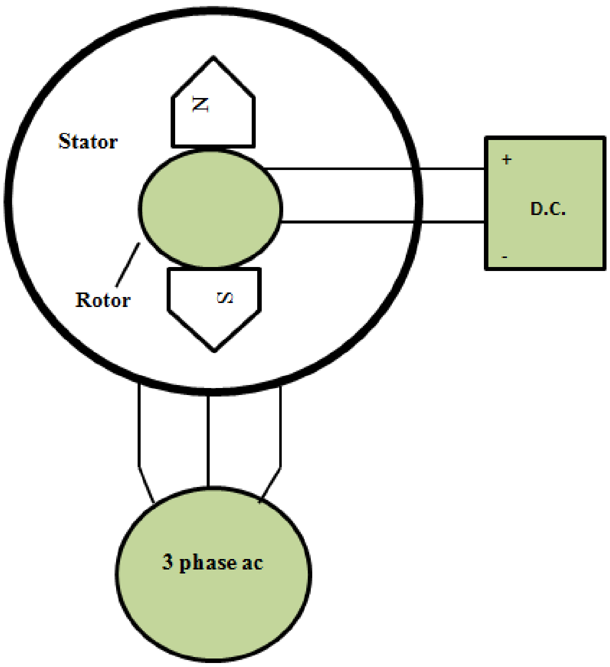

Fig.1 Configuration of synchronous motor

Synchronous motor needs some special methods of starting as it operates at a synchronous speed. Sometimes an induction motor is used to bring it to the synchronous speed. Damper winding or synchronous condenser are also used to start it. Constant speed is a prominent advantage of a synchronous motor. It remains constant irrespective of the load. Synchronous motors also find use in correction of power factor. By the adjustment of excitation current, synchronous motors can absorb or generate the reactive power thus provide power factor improvement. In industrial applications, this feature helps in increasing the power factor to minimize the energy losses and improve the efficiency.

Synchronous motors can operate as synchronous generators also. This feature is widely used in power plants for generating stable voltage and frequency making them apt for maintaining the stability and reliability of power grid. Few of disadvantages of synchronous motors include comparatively high cost and complexity, need a separate dc excitation, need special starting methods, have a limited range of speed.

II. LITERATURE SURVEY

S. Saha and K. Mukherjee introduced the concept by the use of brushless synchronous motor (wound field) as a feasible solution for the EV traction motor. They presented a discussion on comparison between main EV traction machines which are used at present, and then presented configuration of system of the proposed synchronous machine. They used a WRIM (Wound Rotor Induction Machine) for controlling field excitation of WFSM (Wound Field Synchronous Machine), and simulated the control performance using MATLAB (Simulink). They finally presented the comparison, of cost and major performance indices, between the Toyota Prius 2004 machine and the proposed machine [1].

According to S. B. Shahapure and V. A. Kulkarni Deodhar, synchronous motors having exponential performance offer escalating market growth, especially in small RPM and small-to-medium voltage applications. They discussed and demonstrated a 3 phase PMSM motor drive based on field oriented control approach [2].

According to F. Yuan and H. Xiong, traditional control technique of permanent magnet synchronous traction motor pertaining to rail vehicles can barely satisfy high performance control requirements. For addressing this problem they adopted active disturbance rejection controller (second-order) instead of conventional PI regulator for designing the system. They simulated the proposed strategy, in MATLAB/Simulink, by developing a vector control system. Results have shown that the proposed control approach can improve the permanent magnet synchronous motor's control performance [3].

P. Kannojia and K. A. Chinmaya presented a comparative analysis pertaining to energy-efficient motors, including IPM and SPM type Permanent Magnet Synchronous Motors, Switched Reluctance motor, BLDC motor, and the Synchronous Reluctance motor. They carried out design and simulations by the use of Ansys Maxwell software [4].

M. U. Sardar et al. presented and validated a state-of-the-art IPMSM motor designed optimally. It offers larger torque density, larger power factor, efficiency of drive, smaller torque ripples, and smaller magnet volume. They generated the results through FEA analysis, and validated the performance with input of urban drive cycle [5].

S. Zhang et al. addressed the problem of pulsating torque and other losses in PMSM (permanent magnet synchronous motor) due to harmonics present in the stator current of motor caused by nonlinearities of inverter. For addressing this problem, they proposed adaptive harmonic injection algorithm for suppressing the motor's harmonic currents. They established mathematical models of fifth and seventh harmonics of motor, and used Kalman filter based harmonic extraction module for extracting harmonic currents, and compared the results of simulation before and after incorporating the algorithm to verify the effectiveness of this algorithm [6].

D. Zhou et al. presented an optimization technique of HSPMSM (High Speed Permanent Magnet Synchronous Motor). They carried out the parametric modeling of HSPMSM using ANSYS Maxwell finite element simulation software. Finally, they compared high speed motor's performance before and after optimal design. Simulation results revealed that the genetic algorithm & TOPSIS approach improves the high speed motor's multi-objective optimization efficiency, and also weakens the ripple in motor torque [7].

M. U. Sardar et al. used PSO (particle swarm search optimization) for improving the performance of IPM synchronous motor (IPMSM). They improved the performance of IPMSM for large torque output capabilities by the use of permanent magnets, and large saliency ratio for operating in wide range of speed. In this work, they performed PSO algorithm based multiobjective optimization for determining the optimum size of magnets, and used FEA method for checking the results' accuracy [8].

T. Nakamura et al. investigated rotational characteristics pertaining to a 50-kiloWatt-class superconducting high-temperature induction/synchronous motor in the superconducting & the non-superconducting states. They first placed prototype motor in the liquid nitrogen, and obtained the efficiency contour, and then gradually removed the liquid nitrogen from motor under partial load (Ten kilo-Watt) condition. It revealed possibility of the continuous operation even at temperatures above 130 K [9].

C. Liang et al. introduced a dual-3-phase synchronous motor (permanent magnet) into a flywheel energy storage system for yielding higher power output, and lower current harmonics at smaller bus voltage [10].

K. Hu and X. Shen carried out a work on the High Frequency Pulsation Voltage Injection approach based optimization of speed of synchronous motor (permanent magnet), and detection of rotor position. They used a generalized integrator of second order with central frequency varying adaptively in accordance with the speed for extracting the response current signal, and multiplied a square-wave signal (having same frequency) and the extracted signal. Then they built and tested the simulation model, and found, after continuous testing, that by the use of new designed rotor observer, speed convergence time is reduced by 0.79 second at no load starting of the motor, and by 0.6 second in case of sudden rise in load , when running at constant speed [11].

G. Yadagir et al. have carried out a research on mineral extraction in mines using robotic arm. They proposed a solution by the use of AI (artificial intelligence) and PMSM (permanent magnet synchronous motor) for controlling the movement of robotic arm. The proposed system has been made up of robotic arm with many degrees of freedom, PMSM for moving the arm, and the AI algorithms for managing its motion. An excellent control of arm's movements and enhanced effectiveness and precision of mineral extraction procedure is provided by PMSM. The proposed system has many benefits viz. increased efficiency, greater safety, and lower costs [12].

M. P. Nikhila et al. presented a research work on the synchronous reluctance motor associated with an electric four wheeler, and carried out its two-axis modeling. They proposed the synchronous reluctance motors' dynamic behavior by the use of the d-q model. Inductance values corresponding to direct and quadrature axis have been determined from 2D model of the considered motor. The design parameters of motor are affected by many characteristics of electric vehicle viz. size, weight, speed, and gradient. Analysis of performance of the developed motor is done by varying the output parameters viz. speed and torque concerning the input parameters. The validation of the proposed model is done in MATLAB and ANSYS platforms [13].

D. Pasqualotto et al. have carried out a research on synchronous reluctance motor speed control. They presented an extended Kalman filter based sensorless speed control strategy for the synchronous reluctance motor, and proposed a new hybrid algorithm which greatly decreases computational load [14]. R. Lajić and P. Matić presented a system, using the FOC (field oriented control), for position control of the BLDC motor. Firstly, they determined normalized d-q model of motor, and controllers' parameters, then modeled control system using the MATLAB/Simulink, and analyzed the torque & the position angle responses [15].

III. GENETIC ALGORITHM (GA)

The Genetic Algorithm (GA) is an optimization algorithm which is inspired by the principles associated with genetics. They are primarily suited for solving non-linear and complex optimization problems. The operation of GA takes place on a population including potential solutions, representing them as chromosomes. Genetic operations viz. selection, crossover, and mutation are performed on these chromosomes to create new offspring with better fitness. The GA steps are presented in form of a flowchart in Fig.2. The Genetics Algorithm progresses through multiple iterations, termed as generations. In each generation, evaluation of chromosomes is carried out using the objective function (fitness function). New population is produced by genetic operations. The selection process selects the chromosomes having greater fitness values, elevating the chances of convergence to an optimal solution. In the crossover operation, genetic information associated with two parent chromosomes is combined to produce offspring. The mutation operation makes small arbitrary changes in genetic information associated with selected chromosomes. This favors to maintain diversity in population and escape the chances of premature convergence. The process of generation of new population continues until the termination condition is satisfied. Termination criterion may be the highest number of iterations or arriving at specific threshold value of fitness.

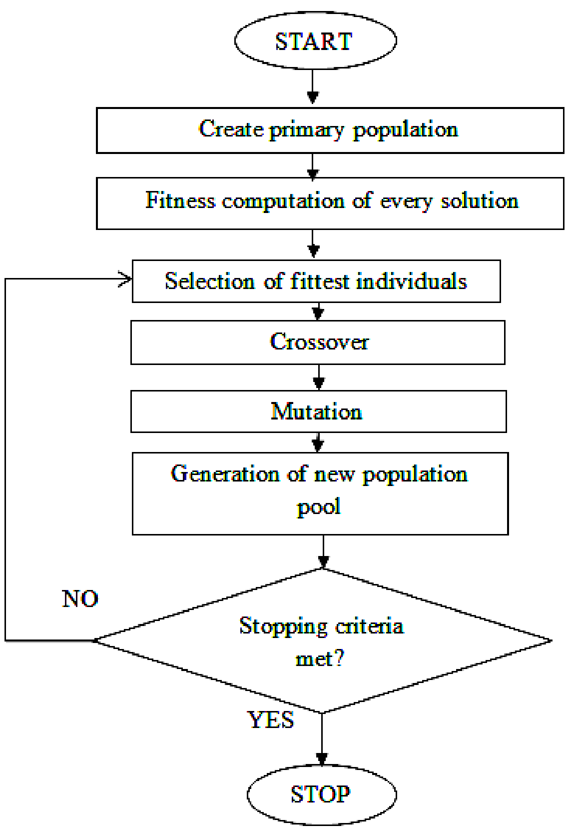

Fig.2 Flowchart of GA

IV. OPTIMIZATION OF ELECTROMAGNETIC TORQUE

The expression of generated electromagnetic torque (T) in synchronous motors is presented in equation (1).

$$T = (K I_f I_a)/s \quad (1)$$

Here K is a constant, and I_f, I_a, and s represent the field current, armature current, and slip respectively. For maximization of torque, the optimal values of mechanical load and field current are to be determined. In this case, a chromosome is comprised of two genes- one corresponding to mechanical load and other to the field current. The values of these genes will determine the respective input parameter. For evaluating the fitness of each chromosome, an objective function, quantifying the torque output, needs to be defined considering the imposed constraints.
On the basis of available date, the formulated objective function to be minimized by GA for the maximization of torque of considered synchronous motor is presented in equation (2). Here m and I_f represent the mechanical load and field current respectively.

$$J = 0.6009 - 0.02095\, m - 0.01513\, I_f + 0.001855\, m^2 + 0.001588\, m\, I_f \quad (2)$$

Now the GA is executed in MATLAB with this objective function with the parameters as presented in the Table I. Various result responses exhibited by 50 iterations of GA execution are displayed in Fig.3.

TABLE I. G A PARAMETERS

Parameter	Value
Population size	50
Creation function	Uniform
Scaling function	Rank
Selection function	Roulette
Mutation function	Gaussian
Crossover function	Two point
Crossover fraction	0.9

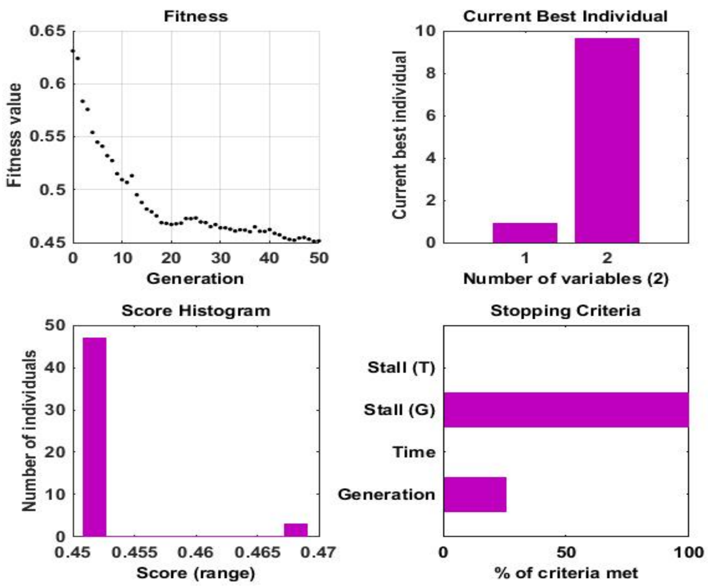

Fig.3. Results of Genetic Algorithm

After termination of GA iterations, the optimal values of mechanical load (m), and field current (I_f) obtained for the maximization of torque are as follows:
m = 0.98 N-m
I_f = 9.7 A

IV. CONCLUSION

This research manuscript aimed to upgrade the performance of a synchronous motor by the use of Genetic Algorithm in MATLAB for finding the optimal values of mechanical load and field current. By developing a fitness function, this approach effectively searched the best values of inputs yielding the maximum torque. The results of this study display the effectiveness of Genetic Algorithm (GA) in maximizing the output torque of a synchronous motor. After multiple generations and selection, the algorithm finally converged to the best values of mechanical load and field current successfully, leading to a remarkable improvement in the performance of considered motor. One major advantage of use of this algorithm in this problem is its ability of exploring a vast range of input combinations and finding the most suitable ones. This allows an exhaustive exploration of solution space which may not be possible or time consuming using conventional optimization methods. The findings of this research work offer valuable insights and contribute to the field of motor's performance optimization.

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