# **CHAPTER 4**

# **OPTIMIZATION AND DESIGN**

## Introduction

In the previous chapter, electrical and mechanical design parameters of the selected axial flux permanent magnet generator are expressed. To do that, mathematical design equations and related drawings are represented. These equations are important for this thesis work. Because they are used in the main design code, which is written in MATLAB. Also in the previous chapter, verification of the given analytical equations of the some important design parameters is given by means of finite element analysis for a sample design. For this purpose, comparison of the design equations and the finite element analysis is made in terms of airgap flux density and induced emf. It’s concluded that the results show good agreement. Therefore, these equations can be used in the optimization algorithm with high accuracy. In this chapter, optimization process of the given design will be summarized and optimum design parameters of the proposed 5 MW AFPM generator will be determined. First, evolutionary algorithms (EA) will be reviewed including the selected genetic algorithm (GA). Then, process of the genetic algorithm based optimization method, which is used in this thesis study, will be explained in detail. Optimization of the proposed generator is constructed with MATLAB optimization toolbox. Also in this chapter, a brief information of this toolbox and used parameters in the optimization algorithm will be covered. Finally, optimized design parameters of the proposed 5 MW 12 rpm AFPM generator will be given. These design parameters will be used for the finite element modelling and analysis in the following chapter.

## Evolutionary Algorithms (EA) and Genetic Algorithm (GA)

There exist different mathematical search algorithms and conventional methods for modern world engineering problems. However, multi-variable nonlinear problems require new methods to avoid from getting stuck into local minimums during optimization process [1]. Main motivation in the Evolutionary Algorithms (EA) is to mimic the nature to find optimum solutions to these problems. EA can be evaluated as direct, stochastic and population-based search algorithm. There are three main rules of biological processes which inspire the EA based search algorithms. These processes can be summarized as follows :

* **Continuous evolution process** , which occurs at the most basic level of “source-code” of living beings, i.e. chromosomes
* **Natural Selection mechanism** , in which the fittest individuals in a society can have more chance to survive and have more robust offspring than those who are not fit at all.
* **Evolutionary process at reproduction** , which is done by the reproduction operators such as cross-over and mutation.

EA mimics the natural selection of living beings. Fittest one in the group has more chance to survive and to be selected. Individuals correspond to encoded solutions of the given problem. Every individual has a fitness value which is calculated by objective function of problem. Algorithm itself evaluates the “adaptive skills” of every indivudials according to this fitness value. Least “fit” individuals are eliminated from the population, hence more adapted and robust individuals replace the old generations. Fitness value is the only required quantitive information about the individual in EAs , contrary to other search techniques such as gradient based optimization methods, in which derivative information is needed [2]. Another advantage of evolutionary search algorithm is that population based evaluation, which is a big computational load advantage over the conventional search algorithms which sample one individual at a time. This population leveled optimization is more advantageous especially when working with large search spaces [3], [4]. In Fig. 4-1, a classification table of search techniques is given.



Fig. 4-1. Classification of search techniques[1], [4]

The most popular search technique among other techniques in the EA family is the genetic algorithms (GA). In this algorithm, individuals are generally represented as fixed-length bit strings as shown in Fig. 4-2 and Fig. 4-3 . Different cell positions in these strings contains information which corresponds to different properties of the individual they represent [4]. Two frequently used operators during the reproduction stage of GA are cross-over and mutation operators. Various “species” or various “solutions” can be obtained during the optimization process by using these two operators. Working principles of cross-over and mutation operators are depicted in Fig. 4-2 and Fig. 4-3, respectively. In cross-over, data interchanges between parents around the crossover point which determined in reproduction stage. However, in mutation, random new data is written to randomly selected locus on the selected “chromosome” or “individual”.



Fig. 4-2. Bit string cross-over operation between parent individuals [4]



Fig. 4-3. Bit string mutation operation [4]

Evolutionary algorithms start with the initial population where values of the initial variables are selected randomly by selection operators based on stochastic methods. Successive generations are created based on the selection and the reproduction principles. Population size is preserved throughout the generations. Algorithm stops when termination criterions are satisfied [3], [4]. These criterions can be different conditions such as predetermined fitness value, predetermined number of successive generation or limited time.

Every problem can be solved by using EA as long as it is expressed with a proper fitness function. User should define a fitness function such that generations could converge to optimal solution. Therefore, every necessary parameter and penalty coefficient corresponding to it should exist in the fitness function maybe not equally but in a weighted form [2]. Penalty coefficients and related definitions will be covered in the following sections. Another advantage of EAs is that it can be combined with other conventional search techniques. EAs are utilized in a parallel fashion in order to evaluate the fitness among the candidate solutions, as mentioned before. Possibility of converging local minimum is decreased due to this parallel process. Because of the high computational burden related to larger search spaces and hybridization processes, distributed computing gaining attention [4]. Also, evolutionary algorithms can easily adapt to changing environment conditions. Therefore, it’s not necessary to restart the algorithm in case of sudden changes as it was in conventional search methods[1].

To sum up, evolutionary algorithms gaining popularity especially in the last two decades due to advantages aforementioned above although first attempts of evolutionary techniques in optimization problems were made in nearly 60 years ago [3], [4]. There are two biggest key aspects of this search technique. One of is that the similarity between the nature during selection and variation stages. The other one is that it is not necessary to provide mathematical information except fitness function in order to evaluate generations of individuals [5]. Additionally, there exist a large application area of this algorithm from medical treatments to advanced engineering problems [6]. This application area seems to enlarge due to new explorations of evolutionary genetics science in biology and increased computer capacities.

## Genetic algorithms based optimization

Genetic algorithms (GA) are stochastic search techniques and exist on the subgroup of evolutionary algorithms. GA was first proposed by John Holland in 1975 with the aim of investigating the usage of natural evolutions on optimization principles [3]. The most salient feature of the GA among the other search techniques is that it doesn’t need derivative information of related search space. This feature helps GA to avoid trapping at local minimums. Algorithm itself based on the three operators namely reproduction, crossover and mutation [7]. As it was in the evolutionary algorithm case, GAs can also explore the search space in a parallel fashion. Another advantage of GA is that optimization procedure can converge to global minimum solution regardless of the starting point. Crossover and mutation definitions are same for the GA as it is mentioned in previous section.

General flowchart of a GA is given in Fig. 4-4. However, it is useful to describe some of the technical terms about GA before continue with the flowchart.

* *Gene* is a parameter which defines the specific trait of the considered solution. For example; stator outer diameter, axial length, airgap flux density. This parameter is encoded in the related locus of fixed-length chromosome.
* *Chromosome* is the combined form of genes, representing a complete “individual”.
* *Locus* is the specific position of encoded data exist in each string of individual or solution.
* *Fitness* is the measure of how suitable a generated solution is. This numeric value is used by the GA when evaluating and selecting the best individuals from the candidate solutions. Because of this reason GA optimizations are usually mentioned with the term “survival of the fittest”.
* *Selection* used in GA is mainly based on stochastic processes and natural similarities. However, there are different selection methods for application such as roulette wheel selection and tournament selection.
* *Population* can be considered as group of individuals in one generation. Large sizes of population leads to longer solution times but larger search spaces.
* *Generation* is the unit of individuals employed in one cycle of optimization. As the evaluated number of generations are increased, more fit solution candidates will be created by the GA.



Fig. 4-4. General flowchart of a GA optimization [8]

## MATLAB GA Toolbox Implementation

## 5MW AFPM generator with optimized design parameters

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