Comparison of Evolutionary and Rule-Based Strategies for Electromagnetic Device Optimization

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Abstract — The use of optimization techniques to improve the design of electromagnetic (EM) devices is becoming very common. However, choosing an appropriate strategy to carry out an optimization process within a practical design activity is still a pending problem. This paper proposes a novel knowledge-based strategy and compares its performance against a standard evolutionary approach. The approaches are implemented as part of a case-based design system and are tested on an induction motor design.

I. INTRODUCTION

The design space of an electromagnetic device is huge and complex since such devices consist of a large number of interacting sub-components and there are strong inter-dependencies among elements related to a variety of physical areas such as mechanical, electrical and thermal. Based on case-based reasoning (CBR), an artificial intelligence methodology that reuses old solutions and adapts them to solve current problems, we have developed an intelligent system to derive candidate devices for a given design task [1] [2]. Since the derived devices are not always optimal, there is a need to "optimize" them in order to better meet the design specifications. Traditionally there are two approaches to optimization, namely, deterministic and stochastic. More recently, a novel optimization algorithm based semantic rules has been developed in [3], which is able to apply domain knowledge to speed up an optimization process.

The goal of this paper is to illustrate the related concepts, techniques and algorithms, and then compare the performance of our rule-based algorithm with a standard evolutionary approach, 1.e. a (1+1) evolutionary strategy.

II. STRATEGIES

The purpose of optimization within a design activity is to find an improved solution for a given task. In general, designers select the deterministic optimization methods if they have information about the derivatives of the requirements with respect to the design parameters; otherwise they prefer to make use of stochastic optimization approaches [4] [5]. However, when facing a complicated problem, such as the optimization of a three phase induction motor, it is not easy to formulate the design problem directly as a traditional optimization task. Often in this situation, designers prefer to take advantage of past experience and related domain knowledge to accelerate the design process of a device. Part of the related knowledge used here is quite "fuzzy" and difficult to code effectively in a computer-based system. In this situation, semantic networks can be employed to organize and represent the domain knowledge because they can provide intuitive and useful representations for modeling the knowledge relating structures and physics and can allow inference through the derived semantic rules. A semantic network is formally defined as a graphical structure for representing knowledge in patterns of interconnected nodes and arcs, in which the nodes represent concepts and the arcs are used to denote the relationships among concepts [6] [7].

III. EMPIRICAL STUDY

This section describes the application of an evolutionary algorithm (evolutionary strategy) and a rule based algorithm in a case-based design system for EM device optimization. An induction motor is used as a test example to introduce the operational details.

A. Evolutionary Strategy

The reason to choose an evolutionary strategy (ES) is that it is a robust general purpose optimization method and will converge to a global minimum. ES is based on a stochastic approach, in which each design variable is represented as a random value. In a general situation, this random character is mathematically expressed as a Gaussian probability density function [8].

In this paper, we have used OptiNet (an optimizer tool which is based on evolution strategy) to carry out a stochastic optimization process to improve the design of an EM device [9].

B. Rule-Based Algorithm

- **A semantic network for an induction motor:** a network is used to represent the domain theory and relationships. Fig.1 represents some typical relations between parameters of an induction motor.

The symbol "+" indicates that the value on the head side increases when there is an increase on the tail side; the "-" denotes that the value on the head side decreases when there is an increase on the tail side.

- **A rule-based inference engine**: a rule-based inference engine has been developed based on the network in Fig.1. Each network link corresponds to a rule and a typical rule is given as follows.

If there is a decrease in air gap length (AG), then the developed torque (TD) will increase.

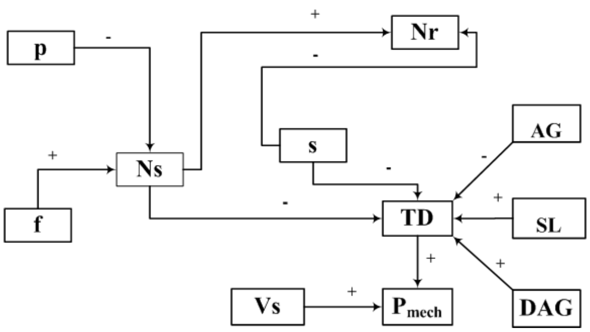

Fig. 1. A part of the semantic network theory for an induction motor

The linked design parameters from Fig.1 are shown in Table I

TABLE I
THE PARAMETERS FOR AN INDUCTION MOTOR SEMANTIC NETWORK.

Symbol	Meaning	Symbol	Meaning
Vs	stator voltage	Pmech	mechanical power
p	pole numbers	f	frequency
Ns	synchronous speed	Nr	mechanical speed
Sl	stack length	s	slip
DAG	the- diameter of AG	AG	air gap length
TD	developed torque		

Jess, a rule engine for the Java platform, has been used to build an inference engine. The rules coded in Jess are used to direct the design parameter modification of process [10].

- **A rule-based optimization algorithm:** we developed a rule-based algorithm to solve an induction motor optimization problem. The inference engine is employed to derive information related to the direction of change of each design parameter within the design space in order to improve the device performance, and expert experiences are used to assign the initial value of a change rate to begin an optimization process.

C. *Preliminary Results*

In our experiment, MagNet (a simulation software tool for electromagnetic fields) is utilized to test and predict the performance of our derived EM device prototypes [11].

For example, in order to solve a single objective optimization problem, such as to find an induction motor with a target mechanical speed of 3314 rpm in the design space, our case-based system first retrieved a very similar case (case 1 with a speed of 3136 rpm) from an existing case base based on the feature (Nr). The retrieved candidate is used as a starting point to launch two respective optimization processes (a rule-based algorithm and a standard evolution strategy) to derive target solutions. The performance of the two optimization processes is shown in Fig.2.

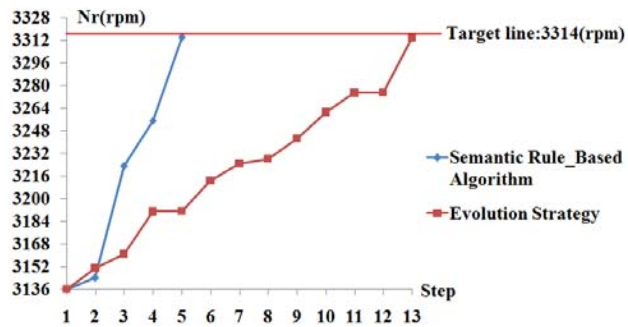

Fig. 2. The performance comparison of optimization processes for two algorithms.

As seen in Fig.2, the semantic rule-based optimization process reaches the target line much faster than the one using the evolutionary ES algorithm. It only takes 5 steps to reach the target solution, while ES needs 13 steps to get to the result.

IV. CONCLUSION

Based on the preliminary experimental results in section III, we can conclude that within a case-based design system, if we can effectively organize and take advantage of domain knowledge, it is truly possible to improve the efficiency and performance of the optimization of a retrieved case which is already fairly close to the target solution. The full paper will provide details of all the algorithms and more experimental results related to multi-objective optimization problems to demonstrate the practical significance of the principles presented in this paper.

V. REFERENCES

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