Niched Genetic Simulated Annealing Algorithm in the Optimization Design of a Permanent Magnetic Actuator for a 40.5kV Vacuum Circuit Breaker

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Abstract—A new algorithm combining genetic algorithm (GA) and simulated annealing (SA) algorithm with significant improvements on efficiency is proposed. Based on the calculation of the electromagnetic field, the optimization design of a bi-stable permanent magnetic (PM) actuator for a 40.5kV vacuum circuit breaker (VCB) is developed.

I. Introduction

Genetic algorithm has a proven efficiency in optimization study of electromagnetic devices. However, the local search ability of GA is not strong [1]. One improvement is to combine GA with other optimization algorithms, such as SA, which models on the annealing process of molten solid. The use of the Metropolis criterion in the improved algorithms allows the acceptance of worsening configurations, commonly referred as "uphill" movements, which are otherwise not permitted in classical optimization methods. In practice, only approximate optimal solution is obtained due to time limitation [1].

In this paper, the niched genetic SA algorithm (NGSA) is described, in which the GA and SA algorithms are combined and the idea of niche is introduced to enhance the search for the optimal solutions. Based on the numerical calculation of the electromagnetic field [2] and the proposed optimization algorithm, a PM actuator for a 40.5kV VCB is designed.

II. Description of the NGSA

Biologically, niche refers to a particular area within a habitat occupied by similar species living together to multiply their offsprings. Even though the mating is random in GA and allows diversity of the primary crosses, a mass of individuals converging towards certain extreme points often result in close breeding. When GA is used in the optimization study of a multi-peak correlation function, many local optimal solutions are found. The introduction of the niche concept can help the GA to obtain all the optimal solutions. The NGSA algorithm can thus be summarized in the following steps:

STEP 1 Initialize the population P_0 randomly with M individuals.

STEP 2 Evaluate all the individuals of the population P_0 and record the first N (N<M) individuals whose fitness are higher than a threshold as better population P_1.

STEP 3 Test the terminating criterion. If the test is passed, go to Step 8, else go to STEP 4.

STEP 4 Execute the processes of selection, crossover, and mutating to produce a population P_2.

STEP 5 Take P_2 as the initial population, use SA algorithm on every individual, and obtain the population P_3.

STEP 6 Combine the population P_3 and P_1 to form a new population P_4 with N+M individuals. Calculate the Hamming distance of every individual, viz.

$$\left\| X_i - X_j \right\| = \left[\sum_{k=1}^{T} (x_{ik} - x_{jk})^2 \right]^{0.5}, \text{ if } \left\| X_i - X_j \right\| < L$$

then compare the fitness of X_i and X_j, and penalize the individual whose fitness is low. ($i=1,2, ...M+N-1; j = i+1,.... M+N; T$ is the number of variables, L is the given distance at the beginning)

STEP 7 Evaluate all the individuals of P_4, record the first M populations with a fitness higher than the threshold. Set $T_{k+1} = \rho T_k$ ($0 < \rho < 1$) and go to step 2.

STEP 8 Output the result and terminate the program.

Table I shows the optimal results and CPU times using SA, GA and NGSA methods in solving the J. D. Schaffe function.

III. The Optimization Design of a PM Actuator

A bi-stable PM actuator for a 40.5kV VCB is studied with the overall size significantly optimized. The volumes of the new PM and actuator are 71.2% and 77.9% of those in the initial scheme. Fig.1 shows the main design variables of the PM actuator (with a total of 12 optimal variables) and its electromagnetic field. Table II gives the comparison of the main parameters in the initial and optimum schemes.

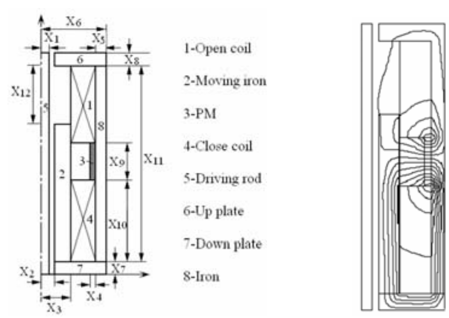

Fig.1 The main design variables of the PM actuator and its field

TABLE I
COMPARISON OF THE METHODS IN SOLVING A STANDARD FUNCTION

Method	Optimum solutions	Maximum	CPU time(s)
Standard	0,0	1	
SA	-1.065×10^{-2}, 6.59×10^{-3}	0.99984	1.47
GA	1.00698, 2.9725	0.990284	1.32
NGSA	9.536×10^{-5}, -9.536×10^{-5}	1.00000	1.28

TABLE II
COMPARISON OF THE INITIAL AND PROPOSED OPTIMIZATION SCHEME

Parameter	X_1 (mm)	X_2 (mm)	X_3 (mm)	X_4 (mm)	X_5 (mm)	Speed (m/s)	Force (N)
Initial	7.0	46.0	102	35.0	78.5	1.36	4139
Optimum	6.01	40.9	89.2	34.6	73.7	1.47	4123

IV. References

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