

PAPER • OPEN ACCESS

## On optimization hydro-generator parameters by NSGA-II

To cite this article: S Gulay and D Verkhovtsev 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **643** 012009

View the [article online](#) for updates and enhancements.

# On optimization hydro-generator parameters by NSGA-II

**S Gulay\* and D Verkhovtsev**

The Institute of Energy and Transport Systems, St. Petersburg State Polytechnical University 29 Polytechnicheskaya St., 195251, Saint Petersburg, Russia

\* E-mail: Gulay@spbstu.ru

**Abstract.** This paper demonstrates the method of optimizing the location and size of the distributed generators with the aim of reducing active power loss by changing the state of the existing tie and sectionalizing switches on the distribution network. A new algorithm is proposed to solve the distribution network reconfiguration problem based on the Runner-root Algorithm (RRA). In the first stage, the Runner-root Algorithm is applied to solve the reconfiguration problem, and the next stage of optimizing the new distribution network configuration takes into account the influence of the location and the size of the distributed generators. The calculation results show that the proposed method can simultaneously solve the problem of optimizing the location and size of distributed generators when reconfiguring the distribution network. The results of the comparison with other studies in the same distribution network system 69 nodes showed that the proposed method is highly effective and can be used for reference in the process of optimizing the operating mode of a distribution network.

## 1. Introduction

A continuously increasing competition at the world market of power plant industry and a growth of electrical energy price form interest to electrical machines parameters optimization. The minimization of production costs (CAPEX) or operational expenses (OPEX) are usually the goal of this procedure. A process of design is connected with a plenty of mutually exclusive requirements and a result with the best ratio of parameters could not be often found by using classical methods. Balanced solution demands more flexible method which allows taking into account the importance of all objective functions. Algorithms for multi-objective optimization with Pareto efficiency are in use for this purpose.

This paper presents an approach of solving multi-objective optimization problem of hydro-generator parameters with the second version of non-dominant sorting genetic algorithm (NSGA-II) [1]. There are three objectives: stator core mass, stator steel losses and rotor current. The magnetic field numerical calculation is performed with the finite-element method in the no-load running with stator winding voltage close to the rated value. The hydro-generator with 640 MW rated power is selected as a design model. ANSYS Electronics Desktop 19 and The MathWorks Matlab 15 were used for a magnetic field modeling and calculation results analysis.

## 2. Calculation capacity and methodology

### 2.1. Optimization algorithm

A hydro-generator main design parameters could be described by vector  $\vec{x}$  which contains  $D$  variables defining geometrical dimension, current density, material properties etc. International



standards, electromagnetic, thermal, mechanical and technological conditions are used for restricting these parameters. Optimization concept is to minimize the vector of objective function  $f(\bar{x})$  with technical parameters fitting acceptable limits.

The general task of multi-objective optimization is formulated as follows:  
parameters vector should be found

$$\bar{x} = [x_1, x_2, \dots, x_D], \bar{x} \in \mathbf{R}^D$$

with  $D$  boundary conditions

$$x_i^L \leq x_i \leq x_i^U, i = 1, \dots, D$$

and  $m$  limitation functions

$$g_j(\bar{x}) \leq 0, j = 1, \dots, m$$

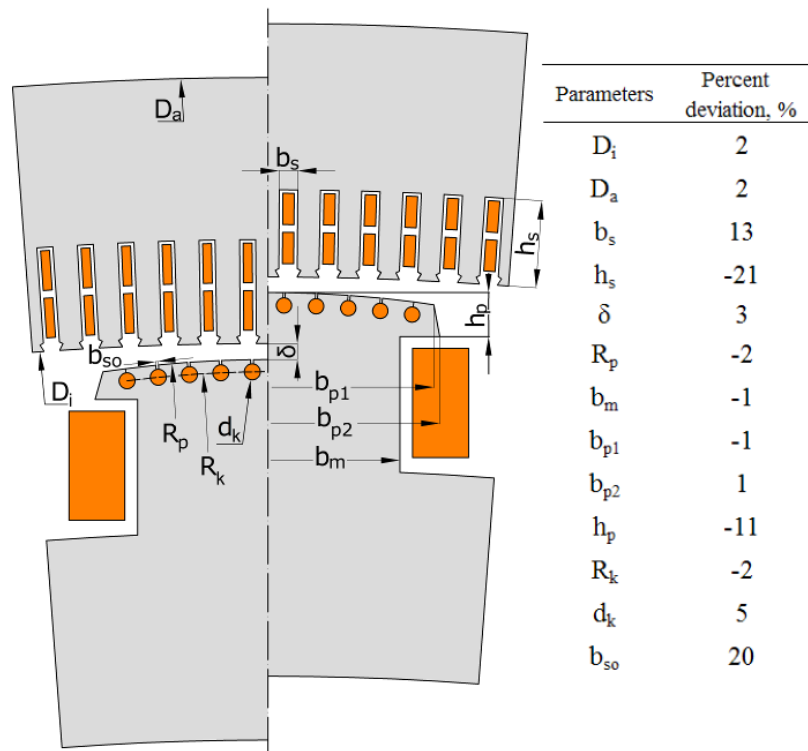
for objective function vector minimizing

$$f(\bar{x}) = [f_1(\bar{x}), f_2(\bar{x}), \dots, f_k(\bar{x})]$$

A solution is Pareto frontier, which is a state of a system when each value of objective functions could not be improved without making others worse.

There are plenty of ways to solve such tasks, but currently metaheuristic methods are mainly used. Strictly speaking, these algorithms do not guarantee an optimal solution determination, however, there is a high probability of it being defined [2]. The non-dominated sorting genetic algorithm, which appeared in 1999 [3], is considered to be the most promising evolutionary method. It was later improved in 2000 and got NSGA-II name. Authors of [4] - [8] demonstrate its efficiency for electrical machines design and power grid optimization.

In the current paper vector  $\bar{x}$  consists of the following design parameters: stator outer and inner diameters, stator core length, stator slot geometry, air gap between stator and rotor, dimensions of rotor pole cores, damper and rotor winding. Parameterized geometrical model is presented in Figure 1. Boundary conditions  $D$  are set as deviations of  $\pm(5 \div 20)\%$  from values, calculated by method [9], depending on the value changing size. The vector objective function  $f(\bar{x})$  and the population size were also set. On the one hand, criteria theoretical number is not limited, but, on the other hand, computational complexity is  $O(kN^2)$ , where  $k$  is the objective function vector length,  $N$  is a number of solutions (population size, number of individual). Thereby,  $k$  and  $N$  are limited by computational power and calculations time, that is why only three criteria were chosen. They describe material usage intensity and overall economic efficiency of design while population consists of one thousand individuals.



**Figure 1.** Parameterized geometrical model: base generator on the left, by algorithm [1] on the right. Percent deviation from the base generator.

## 2.2. Numerical calculation

The numerical calculation of transient magnetic field nonlinear problem was conducted in 2D design. The simulation model corresponds to across sectional area in the middle of stator core length. A magnetic field rotation was assigned for one period with a sample rate 2 kHz, which had been chosen based on the sampling theorem [10]:

$$f_d > 2f \cdot Z / p \text{ [Hz]}$$

where  $f$  - frequency [Hz];  $p$  - pole pair number;  $Z$  - stator slot number.

Hysteresis and eddy-current losses in stator and rotor pole cores were determined by Bertotti equation [11]:

$$P = P_h + P_c + P_e \text{ [W} \cdot \text{m}^{-3}]$$

where  $P_h = k_h B_m^2 f$  - specific hysteresis losses at maximum flux density  $B_m$  and frequency  $f$  [ $\text{W} \cdot \text{m}^{-3}$ ];  $P_c = k_c (B_m f)^2$  - specific eddy-current losses [ $\text{W} \cdot \text{m}^{-3}$ ];  $P_e = k_e (B_m f)^{1.5}$  - specific stray-load losses [ $\text{W} \cdot \text{m}^{-3}$ ];  $k_h$  - hysteresis losses coefficient [ $\text{W} \cdot \text{m}^{-3} \cdot \text{T}^{-2} \cdot \text{s}$ ];  $k_c$  - eddy-current losses coefficient [ $\text{W} \cdot \text{m}^{-3} \cdot \text{T}^{-2} \cdot \text{s}$ ];  $k_e$  - stray-load losses coefficient [ $\text{W} \cdot \text{m}^{-3} \cdot \text{T}^{-1.5} \cdot \text{s}^{1.5}$ ];  $B_m$  - maximum flux density [T].

The correlation between iron losses and flux density at different frequencies (further P(B) curves) was measured by a manufacturer in accordance to the standard [12]. However, it should be mentioned that ring samples magnetic properties determination with Epstein frame does not take into account the influence of the magnetic field rotation on iron losses (rotational hysteresis) [13]. Eddy-current losses coefficient was determined by following expression [14]:

$$k_c = \frac{\sigma \cdot \pi^2 \cdot d^2}{6}$$

where  $\sigma$  - specific electrical conductivity of steel [Sm/m];  $d$  - lamination thickness [m].

Calculation of coefficients  $k_h$  and  $k_e$  is a nonlinear problem that demands using method of finding a global maximum. The genetic algorithm was used to achieve this goal. The condition of maximization of average determination coefficient  $R^2$  of approximating functions and measured P(B) curves was chosen as a fitness-function [15]. Losses coefficients selection for stator steel was performed at the frequency of 50 Hz, as for rotor steel — 400 Hz and 1000 Hz.

Losses were reduced to rated stator voltage with equation [16]:

$$P = P' \cdot \left( \frac{U_N}{U'} \right)^2$$

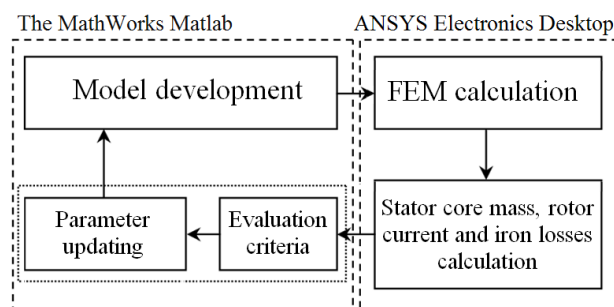
where  $U'$  - calculated stator voltage [V];  $U_N$  - rated stator voltage [V];  $P'$  - calculated iron losses [W].

Rotor current was reduced to rated stator voltage with equation:

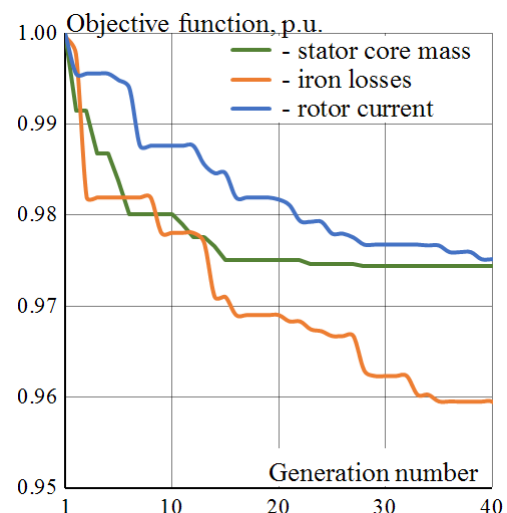
$$i_f = i_f' \cdot \frac{U_N}{U'}$$

where  $i_f'$  - calculated rotor current [A].

The schematic diagram of solving optimization problem is presented in Figure 2. To decrease calculation time the simulation model was reduced to two pole pairs with periodicity conditions being set on their boundaries. The calculation was performed for forty generations with one thousand individuals in each. The criteria behavior analysis shows that steady-state values are archived in the last generation in Figure 3. A parallel calculation using one processor core per each task was applied for solving process acceleration. The total time of computation with a 24-core processor took about two weeks.



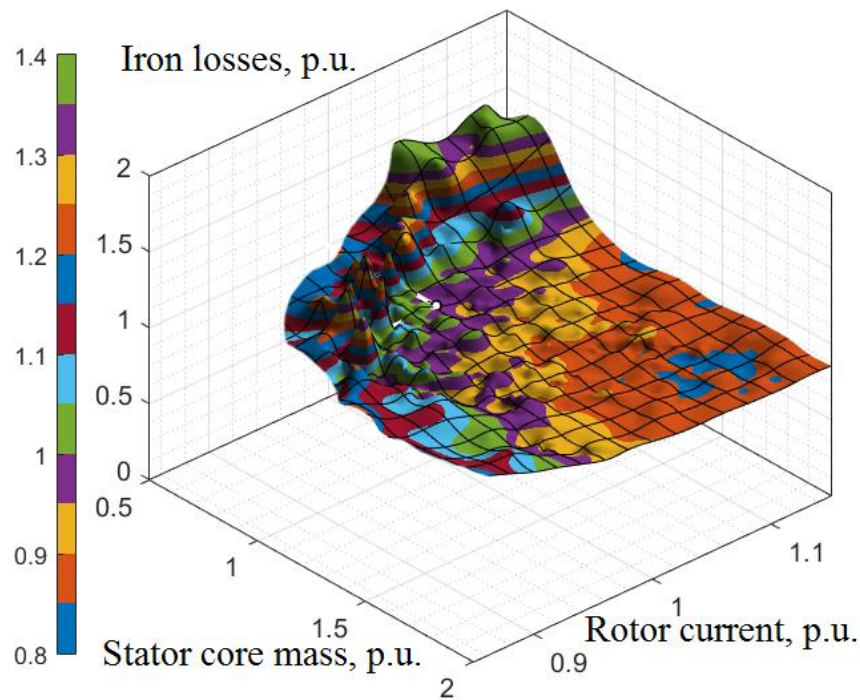
**Figure 2.** The schematic diagram of solving optimization problem.



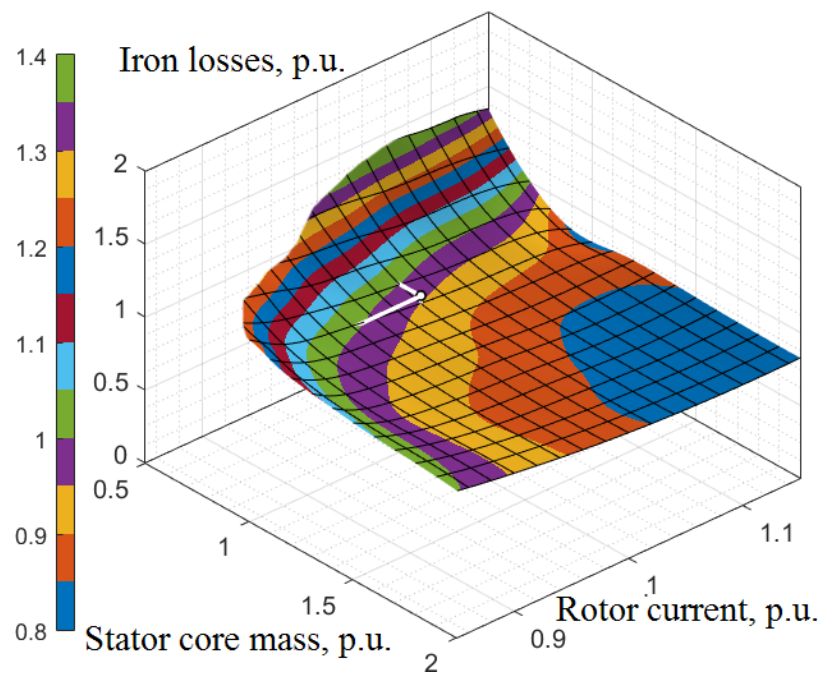
**Figure 3.** Dependences least values of objective functions from generation number.

### 3. Results analysis

The optimization process results are presented in three-criteria space in Figures 4 and 5. The results of numerical calculation of hydro-generator used at the customer's facility and designed according to the method [9], were chosen as base values. The base generator is marked in white.



**Figure 4.** The Pareto-optimal front for the second generation.



**Figure 5.** The Pareto-optimal front for the last generation.

The Pareto-optimal front for the first generation is not presented, because its distribution pattern is random, which is typical for an initial stage of optimization. The population of the second generation is represented in Figure 4, the population of the last fortieth generation is in Figure 5. The distribution analysis shows that the Pareto-optimal state is achieved. A choice of the only solution from a Pareto range could be made by a decision-maker based on his personal assessment of quality criteria and their correlation. This aspect is the hardest for solving of practical multi-objective tasks. It has been poorly researched at a current state [17] and is not considered in this paper.

Nevertheless, the comparison of the Pareto range and the base generator with coordinates (1; 1; 1) shows that the design improvements are possible. For example, the base generator design is presented on the left side of figure 1, on the right — one of models from the Pareto-optimal front. All its criteria are less than a one: a stator core mass 3% less, a rotor current — 2%, iron losses — 1%.

#### 4. Conclusions

An optimization is gradually becoming an important part of modern process of electrical machines designing. Engineers usually rely primarily on previous practice experience which is suitable for a particular task. This “classical” method allows creating operational design, but it does not guarantee optimal usage of materials, efficiency or initial cost. At the same time, these factors are crucial, and they should be taken into account for making an electrical machine more competitive at the world market.

It has been shown the potential for improvement of the hydro-generator design with 640 MW by the genetic algorithm NSGA-II. For example, the base generator criteria were reduced by 1÷3%. Further application of the method will allow minimizing the full range of losses in rated load, thereby to increase efficiency.

#### 5. References

- [1] Deb K, Agrawal S, Pratap A and Meyarivan T 2000 A Fast elitist non-dominated sorting genetic algorithm for multi-objective optimization: NSGA-II *Parallel Problem Solving from Nature PPSN VI. PPSN 2000. Lecture Notes in Computer Science*, vol. 1917 ed Schoenauer M. et al (Heidelberg: Springer)
- [2] Andersen S B and Santos I F 2012 Evolution strategies and multiobjective optimization of permanent magnet motor *Applied Soft Computing* **12**(2) 778–92
- [3] Deb K 1999 Multi-objective genetic algorithms: problem difficulties and construction of test functions *Evolutionary Computation* **7**(3) 205–30
- [4] Ponmurugan P 2012 Multiobjective optimization of electrical machine, a state of the art study *International Journal of Computer Applications* **56**(13) 975–8887
- [5] Alsofyani I M, Idris N R, N Jannati, M Anbaran S A and Alamri Y A 2014 Using NSGA II multiobjective genetic algorithm for EKF-based estimation of speed and electrical torque in AC induction machines *Proc. Int. Power Engineering and Optimization* 396–401
- [6] Belyaev N A, Korovkin N V, Frolov O V and Chudnyi V S 2013 Methods for optimization of power-system operation modes *Russian Electrical Engineering* **84**(2) 74–80
- [7] Belyaev N A, Korovkin N V, Chudny V S and Frolov O V 2014 Clustering of electric network for effective management of smart grid *IEEE International Symposium on Industrial Electronics* 6864921, 1987–90
- [8] Korovkin N V and Potiyenko A A 2002 The use of a genetic algorithm for solving electrical engineering problems *Electrical Technology Russia* **4**
- [9] Glebov I A and Dombrowsky V V 1982 *Hydro-generators* (Moscow: Energoizdat)
- [10] Kotelnikov V A 1933 On the capacity of the ‘ether’ and cables in electrical communication *Proc. 1st All-Union Conf. Technological Reconst*
- [11] Bertotti G 1988 General properties of power losses in soft ferromagnetic materials *IEEE Transactions on magnetics* **24**

- [12] ASTM A343/A343M–03 2008 *Standard Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame*
- [13] Richter R 1935 *Elektrische Maschinen* Vol. 1 (Berlin: Springer) p 209
- [14] Steinmetz C 1892 On the law of hysteresis *AIEE Transactions*
- [15] Hargreaves P A, Mecrow B C and Hall R 2011 Calculation of iron loss in electrical generators using finite element analysis *IEEE International Electric Machines & Drives Conference*
- [16] IEC 60034-2-1 2007 *Rotating electrical machines - Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*
- [17] Noghin V D 2005 *Decision making in a multi-criteria environment: a quantitative approach* (Moscow: FIZMATLIT) pp 10–13