COMPUTATIONAL PROBLEMS OF ELECTRICAL ENGINEERING

Vol. 3, No. 2, 2013

OPTIMIZATION WITH THE USE OF THE GENETIC ALGORITHM METHOD AND PARALLEL COMPUTING

Jarosław Jajczyk

Institute of Electrical Engineering and Electronics, Poznan University of Technology, Poznan, Poland
jaroslaw.jajczyk@put.poznan.pl

Abstract: The work presents the description of a method for performing optimized calculations with the use of the genetic algorithm method performed on computers paralleled in a cluster. It defines the scope of electromagnetic calculations which must be performed in order to determine the objective function. It also provides sample factors describing the quality of paralleling the calculation process.

Key words: optimization, genetic algorithm, computer cluster, parallel computing.

1. Introduction

Computers are widely used in all kinds of problems regarding the design of equipment, selection of components or determination of optimal operation parameters. Thanks to computer technologies, calculation results are obtained faster and with a higher level of precision [1, 2, 3, 4, 5]. Significant computational power of portable devices makes it possible to use them more and more widely. Thanks to that, higher mobility of computation units can be obtained and wireless communication enables cooperation with other devices. The possibility of using computers for numerical calculations is particularly useful in complex problems. In such cases, an analytical solution is often unachievable. However, in the case of numerical calculations, although they make it possible to obtain the result, the waiting time before the solution is obtained is very long due to the complexity of such calculations themselves. In such cases, it becomes beneficial to implement the calculations on parallel computers. Such an approach is particularly useful for performing optimization calculations which are repeated multiple times (thousands of times) in order to determine the optimal solution. This, of course, influences the calculation time making it considerably longer.

Paralleling the calculations is often a problem that is difficult to implement due to the complexity resulting from the need to exchange data between the computation units. Often the time losses resulting from communication between the computers give the opposite result, instead of making the waiting time needed to obtain the solution shorter. An efficient solution of the problem in the case of optimization calculations is combining parallel calculations and optimization with the use of a genetic algorithm. In many cases, the proper configuration of such an algorithm reduces the data exchange between computation units to a value that does not affect the calculation time. Computation acceleration achieved in this way considerably reduces the waiting time before the solution is obtained [2, 5, 6, 7, 8].

The work contains the results of paralleling the optimization calculations of a three-phase unshielded bus duct with solid insulation. The subject of optimization was its geometrical dimensions. The genetic algorithm (GA) method was used as the optimization method. A computer cluster formed by personal computers connected with a broadband computer network was used to run the calculations. The efficiency of the implementation of the optimization analyzed with the use of the genetic algorithm on the computer cluster was examined.

2. Organization of optimization calculations

Optimization with the use of the GA method involves defining the quality factors for the solutions (individuals) that form a specific group (population) of solutions on the basis of which the next population is built [6, 7, 8]. The fact that the calculations of the fitness of particular individuals are performed independently of one another is characteristic of the GA method. This fact can successfully be used to parallel the algorithm.

Paralleling the genetic algorithm can be implemented in many ways. The following could be distinguished: a synchronous centralized organization, a centralized semi-synchronous organization, a distributed asynchronous organization, a network organization, a community organization, and a polled organization. The use of some of those methods results in the need to assure uninterrupted communication and sending large amounts of data between the calculation nodes. The first two of the methods listed above are characterized by the lowest time costs connected with the communication among particular computers [7, 8].

The synchronous centralized organization of a parallel GA algorithm was used in the present work (Fig. 1). In this case, one computer constitutes the central unit where the main process responsible for all genetic operations and for distributing the tasks to other calculation units designated for identifying the fitness characteristics of particular individuals is run [2, 5, 6, 7, 8].

Low demand for computational power of the main process in relation to the subordinate processes prompted the author to run fitness function calculations on the main computer as well.

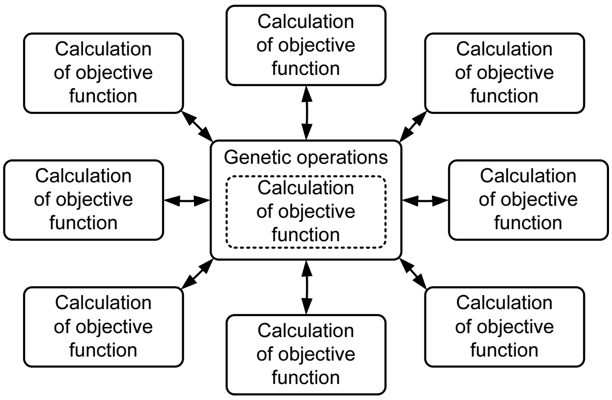

Fig. 1. The organization of the parallel genetic algorithm.

The block diagram of the parallelized genetic algorithm is presented on figure 2.

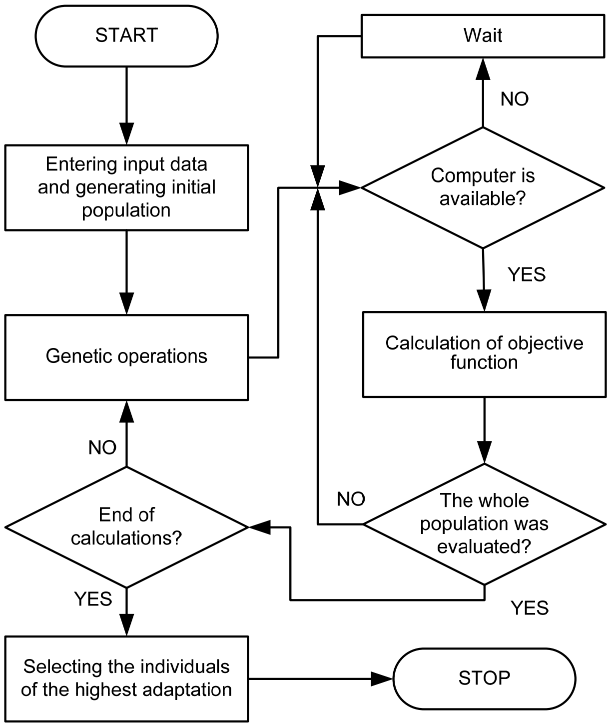

Fig. 2. Block diagram of the parallelized genetic algorithm.

The genetic algorithm is performed on the main computer managing the calculations and responsible for all genetic operations. The tasks connected with calculating the objective function for particular individuals are assigned to subordinate computers. In such an approach, communication between the main node and the calculation units is limited to transferring new task parameters and storing the calculation result which is a single number (the fitness factor).

3. Parallel quality measurements

The quality of paralleling the optimization process per formed with the use of the genetic algorithm method can be determined with one of the basic parameters which characterize parallel algorithms – the task acceleration factor. Its value is equal to the relation of the time needed to complete the task of the size n on one processor to the time needed to complete the same task on p processors and is calculated on the basis of the following dependency (1) [1, 8]:

$$S(n,p) = T(n,1)/T(n,p)\,, \tag{1}$$

where: $T(n,p)$ is the time needed to complete the task of the size n on p processors, n is task size, p is the number of processors.

While evaluating the quality of parallel calculation, its effectiveness (efficiency) expressed as a percentage value and equal to the relation of the acceleration factor of the task with the size of n on p processors to the number of processors p is determined (2) [1, 8].

$$S_{\%}(n,p) = S(n,p)/p \cdot 100\%\,, \tag{2}$$

The efficiency of parallel calculation never reaches 100% due to the cost of communication between the calculation units.

4. The object that is subject to optimization

The advantages resulting from the use of the parallel genetic algorithm were examined on the example of the optimization of the geometrical dimensions of a three-phase unshielded bus duct with solid insulation. Its cross-section is presented on figure 3.

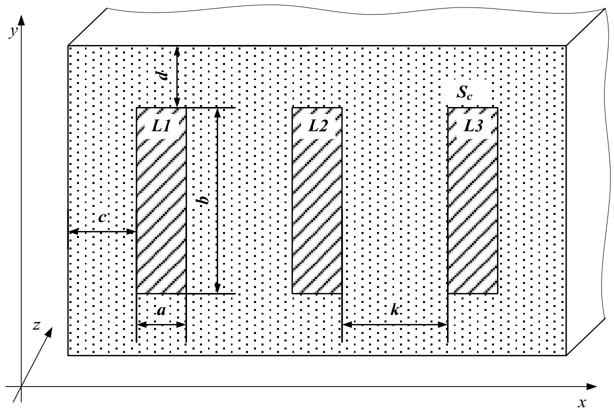

Fig. 3. Cross-section of the high current busduct.

Phase conductors, each of a S_c cross-section area, are embedded in solid insulation, made out of the combination of epoxy resins. The geometry of the system is conditioned by five variables: a, b are the dimensions of the cross-section of a phase conductor; and c, d, k are the dimensions determining the distribution of conductors in the insulation.

All electrodynamics calculations start with defining the distribution of current density $J(x,y)$ in live working conductors with specified phase currents [2]. It can be obtained by solving the system of integral equations (3).

$$\underline{J}(x,y) = -\frac{1}{2\pi} j\omega\mu\gamma \int_{S_c} \underline{J}(x',y') \ln \frac{1}{\sqrt{(x-x')^2+(y-y')^2}} dx'dy' \quad ,(3)$$
$$\int_{S_c} \underline{J}(x',y') dx'dy' = \underline{I}_c$$

where μ is the magnetic permeability of the conductor material; ω is a pulsation; γ is the electrical conductivity of the conductor material; (x, y) denotes the observation point; (x', y')

defines the source point; S_c is the cross-section area of the conductor.

Knowing the distribution of current density makes it possible to determine power losses P_c per one section in particular phase wires on the basis of Joule's law. They are expressed by means of the following dependency:

$$P_c = \frac{1}{\gamma} \iint_{S_c} \left| \underline{J}(x', y') \right|^2 dx' dy' \quad (4)$$

Knowing the approximate distribution of the current density vector makes it possible to determine the bulk density of thermal power ρ_c emitted in the phase wires [2]:

$$\rho_c(x, y) = \left| \underline{J}(x', y') \right|^2 / \gamma \quad (5)$$

Temperature distribution in the system is determined on that basis. It has strong influence on the geometrical dimensions of the bus duct which determines its ability to emit heat. The temperature inside the wires resulting from the active power emitted in the phase wires meets Poisson's equation [2]:

$$\nabla^2 T(x, y) = -\rho_c(x, y) / \lambda_c \, , \quad (6)$$

where: λ_c – the thermal conductivity factor of the phase wire material.

Laplace's equation is met for the temperature parameter inside the insulator and outside the bus duct:

$$\nabla^2 T(x, y) = 0 \quad (7)$$

Thermal energy generated in the phase wires is transmitted to the insulation in which, as a result of heat conductivity, the heat is transmitted to the surface of the bus duct and, then, to its vicinity through convection and radiation. The following equation describes the processes on the bus duct insulation surface [2]:

$$\lambda_i \frac{\partial T(x, y)}{\partial n} = -\alpha_{CR}[T(x, y) - T_o] \, , \quad (8)$$

where: α_{CR} is a heat transmission factor through convection and radiation (the methods for determining it are provided in [2]), T_o is an ambient temperature.

Also electrical stress and the forces operating in the system are included in the calculations. Details regarding the solution of the simultaneous equations (3-8) and the identification of other electrodynamic parameters are provided in work [2].

5. Objective function

In this article minimizing manufacturing costs and using the object over a set period of time while satisfying a set of limitations is assumed the optimization criterion. The objective function (9) is of financial character and it is the function of geometrical variables which influence the size of the bus duct cross section (investment costs), as well as the value of active power losses (exploitation costs).

$$S(\mathbf{u}) = k_{invest.} + k_{exploit.} \, , \quad (9)$$

where: **u** is a decision variable vector; $k_{invest.}$ denotes investment costs, $k_{exploit.}$ defines exploitation costs.

The objective function $S(\mathbf{u})$ that is minimized in the optimization process must meet a series of limitations. The most important of them include: the maximum temperature of the service wire and of the insulator, maximum electrical stress, maximum forces exerted under stable and short-circuit conditions and standard requirements regarding, for example, the consequences of a short-circuit current [2].

6. Calculation results

The goal of the optimization of the geometrical dimensions of the three-phase unshielded bus duct with solid insulation performed in this work is to determine the bus duct whose dimensions would constitute a compromise between exploitation costs (transmission losses) and material costs (investment costs). Details regarding the optimization of the bus duct of this type were provided in [1, 2]. The following values are assumed in the calculations: phase current – 8 kA; wire voltage – 20 kV; exploitation time – 20 years; the wires are made of copper and the insulator is made of epoxy resin.

Calculations were performed on the computer cluster formed of 15 computers connected with a broadband network. The hardware characteristics of the computers used are provided in Table 1.

Table 1

Characteristics of the computers used in the cluster

Processor	Operating system	RAM memory	Number of units in the cluster
Intel i7-2600, 3,4 GHz	MS Windows 7 (64bit)	16 GB	3
Intel i5-3450, 3,1 GHz	MS Windows 7 (64bit)	8GB	9
Intel Core 2 Duo E6850, 3,0 GHz	MS Windows XP (32bit)	4GB	3

Calculations with the use of the genetic algorithm method were performed for 50 generations. Every population consisted of 60 individuals. The calculation time (Fig. 4) and the fluctuations of the acceleration factor and the efficiency of paralleling which depend on the number of nodes (Fig. 5) were analyzed.

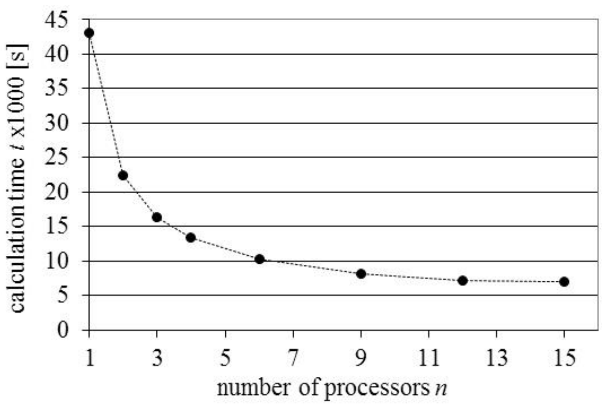

Fig. 4. Calculation time depending on the number of computers.

Firstly, computers equipped with the Intel i7 processor (also the main process was run on such a processor), then computers with the i5 processor, and then the remaining computers were connected.

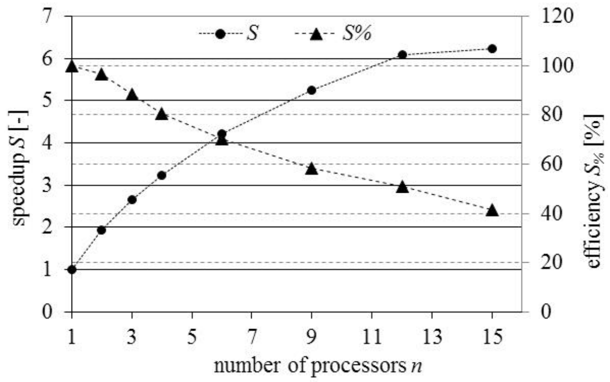

Fig. 5. Calculation acceleration and paralleling efficiency depending on the number of computers.

7. Conclusion

The genetic algorithm is the efficient method of searching for the optimal solution in the global sense. Thanks to the application of parallel calculations, calculation time was reduced from about 12 hours in the case of 1 computer to 1,9 hours for 15 computers (Fig.4.).

Increasing the number of computers comprised in the cluster comprising the cluster accelerates the optimization process. However, the acceleration level does not increase proportionally to the number of computers (Fig.5). It was observed that when 15 computers were used, the acceleration level slightly exceeded the rate of 6. This is reflected in the investigation of the paralleling efficiency factor whose value reached about 42% for fifteen computers taking part in the process of solving the optimization task. Such a low value of the factor is the consequence of the use of the synchronous centralized organization of the parallel genetic algorithm. Great time losses resulting from the need to synchronize the calculations between particular generations lead to the decrease in the quality of paralleling. Further work should be focused on improving this factor.

References

[1] K. Bednarek and L. Kasprzyk, "Speeding up of electromagnetic and optimization calculations by the use of the parallel algorithms", *Przegląd Elektrotechniczny*, vol. 85 , no. 12, pp. 65 – 68, 2009.

[2] J. Jajczyk, "Optimization of the geometry of high currency busducts with solid insulation with the use of the modified genetic algorithm method", PhD thesis, Poznan Univ. of Technology, Poland, 2008.

[3] J. A. Ramirez, R. R. Saldanha, R. H. C. Takahashi and J. A. Vasconcelos, "Improvements in Genetic Algorithms", *IEEE Transactions on Magnetics*, vol. 37, no. 5, pp. 3414 – 3417, 2001.

[4] K. Skowronek and G. Trzmiel, "The method for identification of fotocell in real time", *Przegląd Elektrotechniczny*, vol. 83, no. 11, pp.108–110, 2007.

[5] R. Wyrzykowski, *PC computer clusters and multicore architectures: structure and use*. Warszawa, Poland: Exit, 2009.

[6] D. B. Fogel, *Evolutionary Computation: Toward a New Philosophy of Machine Intelligence.* New Jersey, USA: IEEE Press/Wiley-Interscience, 2006.

[7] D. E. Goldberg, *Genetic Algorithms in Search, Optimization and Machine Learning.* Massachusetts, USA: Addison-Wesley Publishing Company, 1989.

[8] G. Luque and E. Alba, *Parallel Genetic Algorithms Theory and Real Word Applications*. Berlin, Germany: Springer 2011.

ОПТИМІЗАЦІЯ З ВИКОРИСТАННЯМ МЕТОДУ ГЕНЕТИЧНОГО АЛГОРИТМУ ТА ПАРАЛЕЛЬНИХ ОБЧИСЛЕНЬ

Jarosław Jajczyk

У статті описано метод для виконання оптимізованих обчислень з використанням генетичного алгоритму на комп'ютерах, підключених у паралельні кластери. Він визначає обсяг електромагнітних розрахунків, які необхідно виконати, щоб визначити функцію мети. А також він забезпечує зразкові коефіцієнти, що описують якість паралелізації обчилювальних процесів.

Jarosław Jajczyk – PhD Eng., graduate from the Faculty of Electrical Engineering of Poznań University of Technlogy, Poland, the Institute of Electrical Power Engineering specializing in Electrical and Electronic Systems in Industry and Vehicles. He obtained his PhD degree in 2008 and was appointed associate professor in the Institute of Electrical Engineering and Industrial Electronics of Poznań University of Technology. Professor Jajczyk's scientific interests are focused on high current devices and optimization of technical problems, especially with the use of evolution algorithms. He is the author of over 60 scientific works published in conference materials and scientific journals.