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A Computational Tool Focusing the Optimization of 34.5 and 138 kV Overhead Lines Transmissible Power

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Abstract. This paper presents a computational strategy proposal for optimise the physical arrangements of electrical power system overhead lines to increase the power transmission. The technique employs the Genetic Algorithms Theory to find the best geometric arrangement by weighting the optimal phase and sub-conductors spacing as well as the line heights. The target to be achieved is the maximum power at the receiver end. In order to emphasize the approach and the developed computational tool, the methodology is applied to typical 34.5 and 138 kV overhead lines.

Key words

Electrical Power Systems, Genetics algorithms, Optimization, Overhead Lines.

1. Introduction

In recent years studies concerned with the evaluation of different geometrical configurations for transmission overhead lines, aiming at increasing the transmissible power, have been carried through [1]. These new concepts act in the geometric configuration of the conductors, to search for solutions where the distances among phases tend to reduce, whereas the distances between sub-conductors of the same phase tend to increase. This technology is known as HSIL - High Surge Impedance Loading Line. Reference [2] is related to a Russian experience with 500 kV transmission lines and upper. Furthermore, existing literature about the subject [3]-[7] indicates considerable enhancement in transmissible power, as compared to traditional structures.

The energy supply requirements for emergent regions and specific consumer areas situated far away from an existing electrical substation is the main motivation of this work. This challenge arises the idea of carrying out investigations about the best possible physical configuration for 138 kV and 34.5 kV distribution line that would provide, in addition to the economic and feasible construction limits, conditions to supply such loads.

To reach such objectives, this paper presents the basis and the application of an optimization process using the Genetic Algorithm (GA) to find the best constructive arrangement, while keeping in mind the boundary conditions determined by design and operational criteria, amongst other data. This method uses global optimization codes, based on the mechanisms of natural election and the genetics. These codes use a strategy of parallel and structuralized search, which is random and its main target is to find the best possible result toward a given problem [8], [9]. Although the randomness of the process, it adopts historical information to find new points of search, where better performances are awaited, which, in the focused problem, culminates in a geometric configuration that leads to the highest transmissible power for the distribution line in analysis. The GA approach has already been wide adopted for the determination of the best solution for several electrical engineering problems.

To highlight the approach and its potentiality, a software was developed to represent and simulate any power system including several devices. These are: sources, capacitors, reactors, load and the overhead line. This last one is the main target to the optimization approach through the GA method to obtain the best line physical arrangement and the maximum power transmission capability. At the end, typical 138 kV and 34.5 kV overhead line data are used to illustrate the method. By comparing traditional power transmission limits to the optimized values it is possible to conclude about the advantages of finding better configurations throughout the GA.

2. Overhead Lines Capability

This section presents the equations that represent the performance of a transmission or distribution overhead line, focusing its power transportation capability. These equations are based on the classical π-equivalent circuit illustrated in Fig. 1.

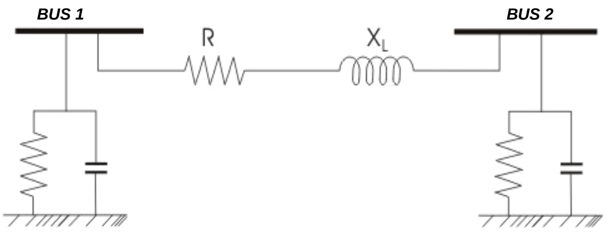

Fig. 1. Typical transmission/distribution line π-circuit representation

The electrical circuit represented by Fig. 1 is bilateral, passive, linear and constituted of two terminals (sending and receiving ends). These characteristics allow these lines to be represented by mathematical quadripoles models. This representation provides great advantages for studying distribution/transmission lines as it is relative simple to insert other parameters or devices, such as: transformer, reactive compensation equipment, other lines, etc.

Several quadripoles models can be used for the representation of the power lines. Among the possibilities, the well-known technique denoted by ABCD, or "generalized constants", is the most popular one.

This ABCD representation is illustrated in Fig. 2. It is derived from the voltage equation (1) and the current equation (2).

$$\dot{V}_1 = \dot{A}\dot{V}_2 + \dot{B}\dot{I}_2 \tag{1}$$

$$\dot{I}_1 = \dot{C}\dot{V}_2 + \dot{D}\dot{I}_2 \tag{2}$$

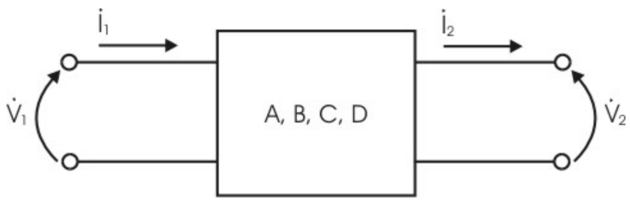

Fig. 2. Typical power line quadripole representation.

The quadripole constants are given by the equations (3), (4), (5) and (6). The parameters A and D are non-dimensional, whereas B is expressed in [Ω] and C in [mho].

$$\dot{A} = A\angle\beta_A \tag{3}$$

$$\dot{B} = B\angle\beta_B \tag{4}$$

$$\dot{C} = C\angle\beta_C \tag{5}$$

$$\dot{D} = D\angle\beta_D \tag{6}$$

In accordance with the length of the transmission/distribution line under analysis (long, medium or short line) these constants are calculated in different ways [10]. For the case of medium length distribution lines, which will be focused in this paper, the quadripole generalized constants can be evaluated as follows:

$$\dot{A} = 1 + \frac{\dot{Z}\cdot\dot{Y}}{2} \tag{7}$$

$$\dot{B} = \dot{Z} \tag{8}$$

$$\dot{C} = \dot{Y}\left(1 + \frac{\dot{Z}\dot{Y}}{4}\right) \tag{9}$$

$$\dot{D} = \left(1 + \frac{\dot{Z}\dot{Y}}{2}\right) = \dot{A} \tag{10}$$

In these equations, Z is the total line impedance and Y is the total line admittance. These parameters are defined by (11) and (12), respectively.

$$Z = (R + j\omega L)\cdot l \tag{11}$$

$$Y = j\omega C\cdot l \tag{12}$$

where R is the resistance, ω is the angular frequency, L is the inductance, C is the capacitance and l the line length.

Therefore, the active power P_2 supplied to the load (usually called of receiver end), can be expressed by (13).

$$P_2 = \frac{V_1\cdot V_2}{B}\cos(\beta_B - \theta) - \frac{A\cdot V_2^2}{B}\cos(\beta_B - \beta_A) \tag{13}$$

In this equation, V_1 is the voltage at the sending end, V_2 is the receiver end voltage, A and B are power line quadripole generalized constants, β_A and β_B are the angles associated to the constants A and B, and Θ is the power line angle.

The maximum active power transmissible (P_{2max}) for a given V_1 and V_2 occurs under the condition imposed by the expression (14).

$$\theta = \beta_B \tag{14}$$

Then, equation (15) provides the evaluation of the maximum transmitted power:

$$P_{2\max} = \frac{V_1 \cdot V_2}{B} - \frac{A \cdot V_2^2}{B} \cos(\beta_B - \beta_A) \qquad (15)$$

The above equations show the relationships between the maximum power and the parameters L and C. As such parameters are strongly affected by the constructive arrangements and constitution of the conductors, the search for the best physical configurations for the phases and their sub-conductors are the target of the optimization process. The details of this implementation are presented in the next section.

3. Software Structure

Aiming at a final product that provides good usability, the developed software, designated by ALPE (High Surge Impedance Loading Line Optimization Software), was developed using Delphi language and the ATP (Alternative Transients Program) platform. Such software is structured as showed in Fig. 3.

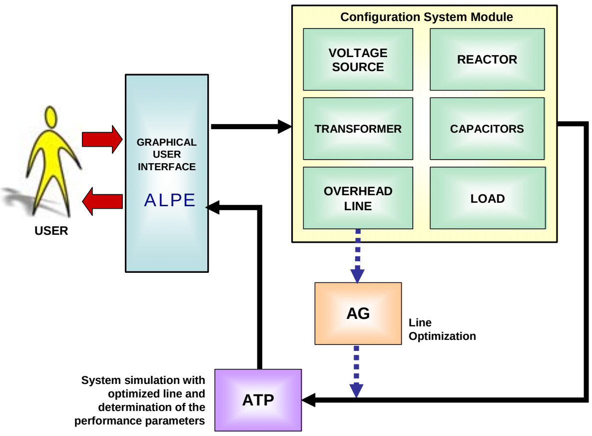

Fig. 3. ALPE Structure

In order to achieve these goals, the final product should prioritize an orienting and friendly graphical user interface. Fig. 4 illustrates an example of a basic power system representation at the ALPE.

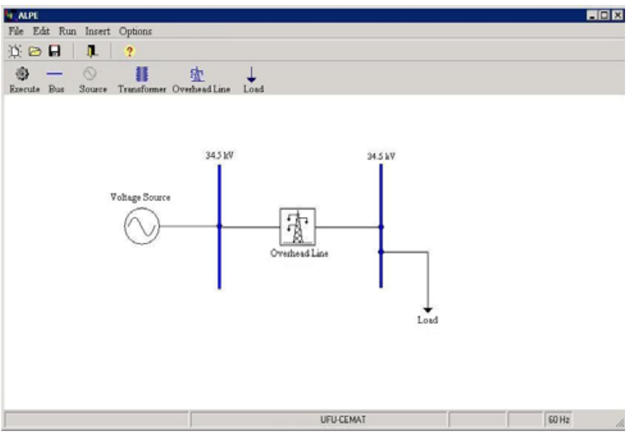

Fig. 4. ALPE software– Basic 34.5 kV Power System representation

As it can be seen, the ALPE is basically constituted of the following parts:

A. Configuration System Module

The Configuration System Module enables the power system representation that involves its constituting elements inserted within the typical moulds of the available library provided by the ATP simulator, with a few particularities added to the sought applications. Towards this, the network components used correspond to those already made available by the computational basis library employed.

This module is intercommunicated with an optimization package that is based on a search method called Genetic Algorithms which provides the best geometric arrangement by weighting the optimal phase and sub-conductors spacing as well as the line heights aiming at achieving the maximum power at the receiver end.

B. Optimization of Overhead Lines Designs by Genetic Algorithms

Genetic algorithm consists of a random search method, based on the natural election concepts [8]. This technique adopts a strategy of parallel and structuralized search through the use of probabilistic rules to solve complex optimization problems [9]. This approach is attractive to solve problems containing the following characteristics:

- Several parameters to be considered;
- Several variables or characteristics to be agreed during the search of the best solution;
- Many restrictions or conditions that cannot be easily represented by mathematical expressions;
- Large search spaces.

In this context, the questions associated to enhancement of the overhead lines capability as already mentioned, involve a variety of possible geometric compositions of the phases and sub-conductors. Thus, procedures based on systemized optimization techniques, such as the GA, can be adapted to the strategies required here.

The starting point for the GA application is the mathematical representation of the problem such as the physical constructive data, the electric characteristics, as well as the design restrictions, security criteria and others.

To cope with the above, mathematical calculations can be implemented to handle overhead lines characteristics and parameters, conductors, phase and sub-conductor spacing, height, etc. These parameters lead to the lines characteristic data (R, L and C) and these, jointly with the voltages, determine the fitness function (15). This equation allows for the calculation of the maximum transmissible active power. The solutions that better satisfy to this equation are called individuals. Such individuals are codified through the concatenation of the mentioned variables in a binary number vector, in which, each set of 10 bits corresponds to specific values for the phase spacing, height and the distance between the sub-conductors, respectively.

The GA, basically, creates a set of possible solutions. Next, through an iterative computational process that considers and respects the characteristics, the configurations, the limits and the imposed restrictions will automatically be tested considering the required features.

Each iteration is called generation and, in each one, the best two individuals providing the better transmissible power are protected. These values are stored to a new generation to share a recombination of the individual's mathematical information and, consequently, to complete a new set of solutions to be, again, tested. In the sequence, new tests and recombination are performed and new generations are created throughout the process. At the end of the process, the maximum transmissible power is pointed out together with the best phase tower position, as well as the sub-conductor configuration.

The Fig. 5 illustrates the GA basic structure.

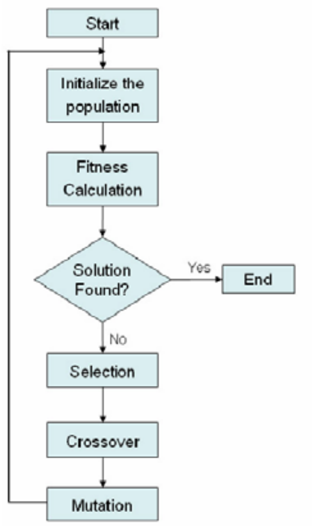

Fig. 5. Genetic Algorithms basic structure.

Focusing the specific application of this work (the search for the best configuration for overhead lines), the approach, initially, is strictly applied to find out the phase and sub-conductor spacing as well as the phase height, with other parameters kept constant all over the calculation.

C. ATP Simulator (Alternative Transients Program)

For the overhead line component, its modelling is based on the classical π-equivalent, which is available on the ATP library. Then it is possible to input the conventional parameters manually and run the simulator with the original data. Furthermore, for this component, the best physical arrangements for the overhead line can be found by the GA optimization module, providing the new R, L and C parameters to be inserted, automatically, in the ATP card. This feature allows the comparison performance between the traditional line configurations with the optimized ones.

Thus, after the power system insertion, the ALPE runs the ATP, imports the results and finally shows the electrical performance of the system under analysis.

4. Case Studies

In order to illustrate the applicability and the potentiality of the adopted optimization method, two commercial lines studies are focused. They correspond to Case 1 and Case 2, respectively.

A. Case 1 – 34.5 kV

The first application consists in a 34.5 kV power line which, in its conventional form. It is constituted by a horizontal arrangement for the phases, with 4 (four) sub-conductors per phase, without lightening conductor. The conventional main characteristics of this line are described in Table I.

TABLE I
34.5 KV CONVENTIONAL OVERHEAD LINE DATA

Phases height from the ground	9.60m
A, B, and C phase spacing	1.10m
Distance between sub-conductors	0.10m
Catenaries	1.40m
Span between towers	150 m
Line length	100 Km
Earth resistivity	2000 ohm.m
Conductor adopted in the transmission	4/0 AWG CAA
Phase-to-Phase line voltage	34.5 kV

Under these conditions, the conventional line has a maximum transmissible power of 30.5 MW. This value will be adopted as reference for comparison with the results given by the optimization process.

In order to search for the optimized line configuration, by double clicking the icon given in the main screen associated to the ALPE package as given in Fig.6, it is possible to feed the program with the constructive and electrical parameters to be used as initial conditions.

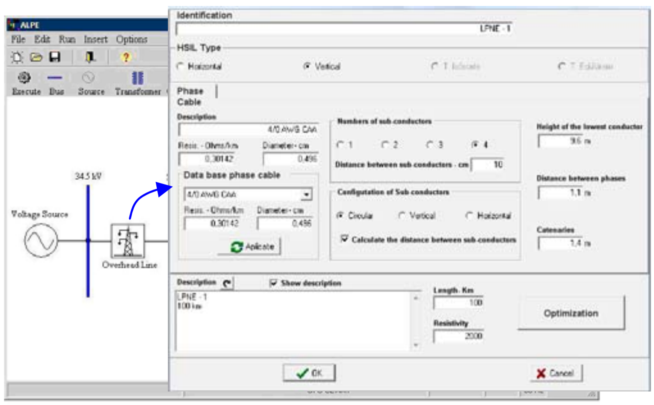

Fig. 6. ALPE – Initial 34.5kV overhead line configuration

In the sequence, based on the GA optimization technique, the ALPE calculates the best power line physical arrangements in order to provide the maximum transmissible power by a click on the Optimization box, as illustrated in Fig. 7. To achieve this goal, in addition to the previous initial conditions, other boundary limits are supplied to the software. These are also shown on the left hand side of the above figure. After that, the software shows the line parameters results associated with the physical structure that best fits the imposed requirement, i.e. the highest transmissible power. They are given on the right hand side of the same figure.

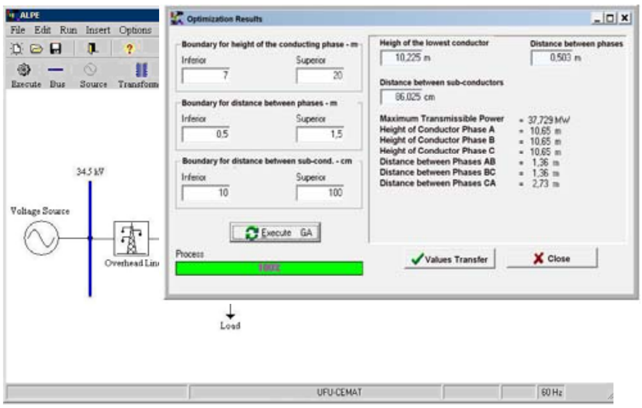

Fig. 7. ALPE – 34.5kV overhead line optimization

As previously mentioned, the following parameters were taken as GA variables: phase spacing, height and sub-conductors distance. After going throughout a convergence process a final solution is reached. For the present application the optimized configuration data is summarized in the Table 2.

TABLE II
34.5 KV OVERHEAD LINE OPTIMIZED DATA

Phases Height from the ground	14.72m
A, B, and C Phase Spacing	1.50m
Distance between sub-conductors	0.99m
Catenaries	1.40m
Span between towers	150 m
Line Length	100 Km
Earth Resistivity	2000 ohm.m
Conductor adopted in the transmission	4/0 AWG CAA
Phase-to-Phase Line Voltage	34.5 kV
Maximum Transmissible Power	37.8 MW

It can be noted that the distances between the phases were modified from 1.1m to 1.00m and the distance between sub-conductors from 10cm to 50cm. This new configuration resulted in the increase of 24% for the maximum transmissible power: the original value of 30.5 MW went up to 37.8 MW. Moreover, for the given application, the voltage regulation is around 10%, whereas the efficiency reached 93%.

It is important to emphasize that such values are associated to the fact that the conductors and sub-conductors were kept the same as in the original form. Naturally, any change on the conductor cross section will bring subsequent variations of these results.

In addition to the above comments it should be kept in mind that other configuration concerning physical phase arrangements (triangle, vertical, etc.) or conductor cross section, among others, may lead to distinct performance in relation to the power increase, regulation and efficiency.

It must be emphasized that the developed software also allows for the time domain operational overall system analysis. Therefore, additional information about the arrangement performance can be readily obtained, however, due to the lack of space, only the optimized configuration has been focused.

A. *Case 2 – 138 kV*

Table III indicates the main characteristics related to a typical 138 kV distribution line arrangement. It consists of a balanced triangle configuration, containing 4 (four) sub-conductors and a lightning cable conductor.

TABLE III
138 KV OVERHEAD LINE CONVENTIONAL DATA

A Phase Height	19.90m
B Phase Height	18.00m
C Phase Height	21.80m
Distance between phases and structure	2.74m
Distance between sub-conductors	0.20m
Catenaries	1.40m
Span between towers	150 m
Line Length	100 Km
Earth Resistivity	2000 ohm.m
Conductor	336.4 MCM CAA
Lightning conductor	4/0 AWG CAA
Line Voltage	138 kV

Using the above data, the conventional 138 kV line has a maximum transmissible power of 518.75 MW. Once again, this is the value to be adopted as reference for comparative studies.

A better performance for this distribution line was then searched using the ALPE software. Following the same previous steps as for Case 1, the final optimized configuration is given in the Table IV.

TABLE IV
138 KV OVERHEAD LINE OPTIMIZED DATA

A Phase Height	15.46m
B Phase Height	17.70m
C Phase Height	19.94m
Distance between phases and structure	1.94m
Distance between sub-conductors	0.99m
Catenaries	1.40m
Span between towers	150 m
Line Length	100 Km
Earth Resistivity	2000 ohm.m
Conductor	336.4 MCM CAA
Lightning conductor	4/0 AWG CAA
Height of lightning conductor	21.06m
Line Voltage	138 kV
Maximum Transmissible Power	695.42 MW

The results are clear enough to demonstrate that the distance between the phases and the structure was modified from 2.74m to 1.94m. The distance between the sub-conductors, originally of 20cm, was changed to 99cm. This new configuration resulted in 34% of increase for the maximum power transmissible: the previous value of 518.75 MW went up to 695.42 MW. For this condition, the voltage regulation is 4.6% whereas the efficiency is 96.8%.

5. Conclusion

The present paper focused in the use of an optimization technique, based on genetic algorithms, for the search of the best constructive geometric configuration of 34.5 kV and 138 kV overhead electrical power systems distribution lines. The strategy produced a computational program called ALPE witch allows for searching the best physical line constructive parameters that give the highest power transmission to be transferred from the sending busbar to the receiving end one. The approach has been based on the Genetic Algorithm Method which has been proved to be a useful tool towards the paper target.

To illustrate the achievements and the application of the considered procedure, two power system distribution lines, one of 34.5 kV and another of 138 kV, were taken as examples of distribution lines to be optimized. The final results obtained for the studied cases have pointed out 24% and 34% of power increase for the 34.5 kV and 138 kV lines, respectively.

The method application was carried out to find out the best line constructive configuration as far as phase and sub-conductor spacing and phase's height from the ground are concerned. Although these were the variables chosen to be optimized in this paper, it should be stressed that other variables such as design restrictions, voltage regulation limits, minimum efficiency, thermal limits, mechanical restrictions, economic feasibility, etc could also be simultaneously taken into account. The present work is to be further developed so as to include such conditions.

References

[1] F. C. Dart, L. A. M Domingues, C. R. N. Barbosa, O. R. Júnior, A. P. Neto, S. J. G. Cavalcanti. "New Technology Validation for Transmission in 500 kV" (*in Portuguese*), XV Seminário Nacional de Produção e Transmissão de Energia Elétrica, Foz do Iguaçu, Brasil, 1999.

[2] P.C.V. Esmeraldo, C.P.R. Gabaglia, G.N. Aleksandrov, I.A. Gerasimov, G.N. Evdokunin. "A proposed design for the new Furnas 500 kV transmission lines-the High Surge Impedance Loading Line", IEEE Trans. Power Delivery, vol. 14, pp. 278-286, Jan. 1999.

[3] G.N, Alexandrov; G.V Podporkyn, "Improvement of the efficiency of 35 to 220 kV lines" AC and DC Power Transmission, International Conference on Pages 226 - 231, September 1991.

[4] F. Dart, L. A. C. Domingues, A. R. C. Carvalho, W. W. Ping, F. P. Salles, J. C. S. Filho, O. R. Júnior, , A. P. Neto, S. J. G. Cavalcanti. "New concepts of transmission lines – impacts on the studies of planning and analysis of systems" (*in Portuguese*), XV Seminário Nacional de Produção e Transmissão de Energia Elétrica, Foz do Iguaçu, Brasil, 1999.

[5] C. Portela, S. G. Júnior. "Non-conventional lines with raised transmission capacity - parametric Analysis" (*in Portuguese*), XV Seminário Nacional de Produção e Transmissão de Energia Elétrica, Foz do Iguaçu, Brasil, 1999.

[6] H. C. Coelho, "Nova LT – A New concept of transmission lines" (*in Portuguese*), XVII Seminário Nacional de Produção e Transmissão de Energia Elétrica, Uberlândia, Brasil, 2003.

[7] F. C. Dart, J. I. S. Filho, R. M. Azevedo, A. R. Carvalho, O. R. Júnior, P.C.V. Esmeraldo. "Projects of non-conventional of transmission lines - an alternative to be considered in the planning of the expansion of the Brazilian electrical system" (*in Portuguese*) X Simpósio de Especialistas em Planejamento da Operação e Expansão Elétrica, Florianópolis, Brasil, 2006.

[8] J. H. Holland. "Adaptation in Natural and Artificial Systems". University of Michigan Press, Ann Arbor, Mich., 1975.

[9] D. E. Goldberg, "Genetic Algorithms in Search, Optimization and Machine Learning". Addison-Wesley Publishing Company, Inc. USA, 1953.

[10] R. D. Fuchs. "Electric Power Transmission: Overhead Lines; Theory of Steady State Lines Operation" (*in Portuguese*) Rio de Janeiro, Livros Técnicos Científicos, 1977.