Evolutive Algorithm for Power flow optimization

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***Abstract*—The actual lines have many operation problems like power flow distribution, oscillations... A bad power flow distribution on the network lines appears for example during a fault, in this case is posible that some lines of the network would be overloaded and other lines under their thermal value. A posible solution of the problem is using series compensators to redistribute the power flow, the converters are bypassed until the fault appears and after this, it start to compensate. Evolutive algorithms can solve the problem of the ubication in the network of these converters and to chose the power of it too, minimizing the total installed power to make that power flow redistribution.**

This paper presents an evolutive algorithm that solves the problem of placing SSSC converters in a network to optimize the power flow across all the lines of those network, minimizing the total installed power when a line of the network falls. The number of converters to be placed and their power will be chosen by the algorithm too.

I. Introduction

As deregulation of the electric system becomes an important issue in many countries, Flexible AC Transmission System (FACTS) [1], [2] devices become more and more commonly used. They may be used to improve the transient responses of the power system and can also control the power flow (both active and reactive power), this is very important because the reactive power also increases the transmission losses [3] and the control of active power flow requires "series VAR" solutions, that can alter the impedance of the power lines or change the angle of the voltage applied across the line.

Static Series Synchronous Compensator (SSSC) is a based on a solid-state controllable voltage source inverter that is connected in series with power transmission lines. SSSC has become an effective tool for power flow control [4], [5], because it can inject a voltage in quadrature with the line current, so the line reactance can be changed from capacitive to inductive or from inductive to capacitive, using this converter.

Series reactive compensation has rarely been used other than on long transmission lines due to the high cost and complexity of implementation. The main advantages of FACTS are enhancing system flexibility and increasing the loadability. Although FACTS devices have many advantages, they are handicapped due to the high cost of the components.

Many techniques have been used for the planning of series compensation: heuristic [6], artificial intelligence techniques such as: Simulated Annealing [7], Tabu Search [8], Evolutive Programming [9], Fuzzy Logic and Evolutive Programming [10], Fuzzy logic and micro-GA [6] and Genetic algorithms [11],[12],[13]. These techniques have been used recently to locate capacitor banks [14], [15].

For complicated networks the heuristic methods that try to minimize the cost of the investment and the genetic algorithm based on techniques [16] are good solutions. But when the problem becomes more complicated, evolutionary algorithms based on techniques have provided better results [17]. The evolutive strategies (EE) are probabilistic optimization techniques [18] based on natural selection and evolution of living beings.

This paper presents an algorithm based on evolutionary techniques to do a series compensation in a network that has lines loaded above their nominal value, trying to minimize the installed power. The number of converters to be placed and their power will be chosen by the algorithm. This problem is proposed by Red Elctrica de España (R.E.E. spanish T.S.O.) to ensure that no line is above its nominal value in fault situations in the network.

II. Approach to the problem.

R.E.E. proposed a network that is used in general situations, Fig. 1 represents the general diagram of the system. The network consists of three nodes, with five interconection lines. In node 3, there is a load represented by their impedance, node 1 is a emiter node and node 2 is a reciever node. The problem is produced when a three phase fault appears in a line, the algorithm studies all the posible lines falls (but only one line in each time) in order to give a series compensation solution, minimizing the total installed power.

Table I shows the powers (nominal and actual) flowing across the lines, that is without a line fall. So the problem is that is posible that a line will be overloaded while the other lines are below their nominal power values, so the ojetive of the algorithm is to modify the power flow distribution in all the network posible situations using SSSC converters to ensure

978-1-4244-4649-0/09/$25.00

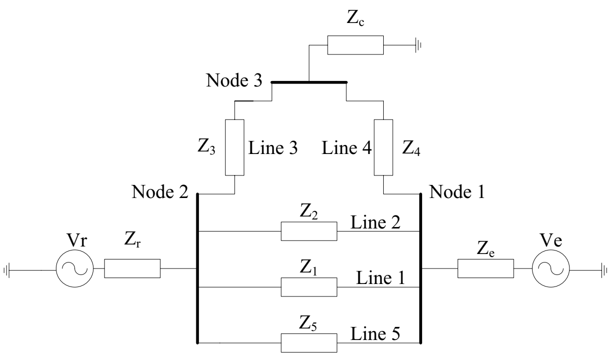


Figure 1: Electric system

that all lines are below their load limit. So really the algorithm solves five situations one per each line:

- case1: Line 1 falls
- case2: Line 2 falls
- case3: Line 3 falls
- case4: Line 4 falls
- case5: Line 5 falls

Table I: Table of powers in normal situation.

Line	$S_{nominal}$	S_{real}
1	55 MVA	41.77 MVA
2	81 MVA	50.86 MVA
3	81 MVA	11.95 MVA
4	81 MVA	49.05 MVA
5	70 MVA	50.86 MVA

III. Proposed Evolutive Algoritm.

The structure of the algorithm is the same used in [19]: Generate the initial population, evaluation of the solutions, generate descendants, mutation of the descendants, selection and finalization. The power of this algorithm is that with the same structure it can be used to solve different problems. It is necessary to change only the chromosomes (matrix dimensions) and the solution of the power flow. In some cases the function which assings the cost to each chromosome should be changed too, but the idea is the same.

One of the most important things in this types of algorithms is the codification of chromosomes, the proposed algorithm uses the codification shown in Table II, where each column represents a gene of the chromosome. ΔX_i are the equivalent impedance of the SSSC converter in the line “i”, σ_i the standard deviation of a normal distribution which determines the mutation of the impedance in the line “i”. This represents the structure of a chromosome and every individual is represented in this way.

With the lines impedances and the increase or decrease of this impedance produced by the converter, the elctric system variables to solve the problem like voltages, currents and powers: S_i, S_{ci}, S_{TC} can be calculated.

Table II: Table chromosomes codification.

ΔX_1	ΔX_2	ΔX_3	ΔX_4	ΔX_5
σ_1	σ_2	σ_3	σ_4	σ_5

A. Generate initial chromosomes

At first, the initial μ individuals must be generated. The proposed algorithm is an $(\mu+\lambda)$ evolutive algorithm, with $\mu < \lambda$, that is because in this techniques is recommended to use more generated population than initial population. In this example μ and λ are small numbers too, because this problem is a small one (the network has only three nodes), so it is not necessary to use a big number of individuals.

The initial choromosomes paremeters: ΔX_i and σ_i are generated randomly, this is for all the initial population.

B. Solving Power Flow: Evaluation of the solutions

Now, the other chromosomes parameters: Power across each line: S_i and the power of the converter installed in each line too: S_{ci} must be calcultated. With the value of the increased or decreased impedance in each line, a power flow is solved to obtain the power in each line, the power of the converters and the total power installed.

Table III: Table of the network paremeters to solve the problem.

S_1	S_2	S_3	S_4	S_5
S_{c1}	S_{c2}	S_{c3}	S_{c4}	S_{c5}

With the power flow, the voltages on the nodes: V_{N1} and V_{N2}, and the line currents: i_1, i_2, i_3, i_4 and i_5 can be calculated. With these voltages anf currents, the powers of the lines S_1, S_2, S_3, S_4, S_5 are calculated.

FInally, to complete the parameters of the network, the power of the SSSC converters: S_{C1}, S_{C2}, S_{C3}, S_{C4}, S_{C5} and the total installed power S_{Ctot}, should be calculated.

This calculus is done with all the initial population to obtain all the parameters of the initial space. To evaluate wich solution is the best, a “fitness function” asingns a cost to each chromosome.

$$cost = \sum S_{ci} + \Psi \quad (1)$$

The Eq. 1 shows the form of the fitness function which has two terms: the total installed power, and a term Ψ which represents the cost assigned to each chromosome to overcome the nominal power value of the lines, called as: “penalization function”. This function uses the quadratic error to assign the cost to each individual.

In another point of the algorithm another power flow equal to this one is solved by the λ new individuals asigning their cost too. It is important to say that the power flow to solve is different for each case.

C. Generate descendants: Crossover operation

Now the λ chromosomes "descendants" should be generated from crossings between the chromosomes μ "parents". First, two parents are selected randomly, these chromosomes generate two descendants; to create the first column of the "Descendant 1" randomly the first column of the "Parent 1" or for the "Parent 2" was selected (randomly). The first column of the "Descendant 2" is the first column of the other parent (the no selected).

This is done with all the columns and until all the chromosomes "descendants" λ are created. The Fig. 2 shows an example of de generation of two descendants by the crossover operation.

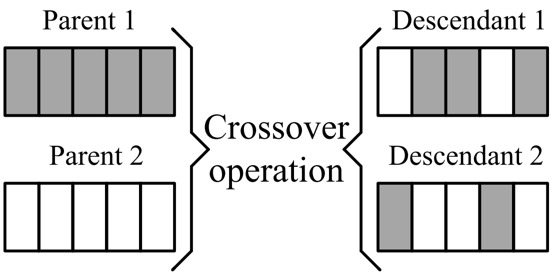


Figure 2: Crossing operator.

D. Mutation of the descendants

To solve the problem, its necessary that the impedance that brings the converters varies, so its value must change. In this section it will be explained how this variation is done. First, two random variables z_0 and z_i with a normal distribution with average zero and typical desviation τ_0 and τ_i respectively, are defined as shown in Eq. 2. The bibliography recommends the values τ_0=0.1 and τ_i=0.3.

$$\begin{gathered} z_0 = \tau_0 \cdot N(0,1) \\ z_i = \tau_i \cdot N(0,1) \ \textit{whith}\ i = 1,...,5 \end{gathered} \tag{2}$$

z_0 will remain fixed for all the chromosomes genes, but z_i varies for each gene with the expression Eq. 2.

After this, the values of the cumulative probability of the variation of the impedances: σ Eq.3 and the new impedances values ΔX Eq. 4 are calculated for each gene of the chromosome.

$$\sigma_{i_{n+1}} = \sigma_{i_n} \cdot \exp\left(z_0 + z_{i_{n+1}}\right). \tag{3}$$

$$\Delta X_{i_{n+1}} = \Delta X_{i_n} + \sigma_{i_{n+1}} \cdot N(0,1). \tag{4}$$

This calculation is done for all the values of each chromosome impedances, and for all the λ chromosomes obtained by the crossing operation.

IV. Selection function

In this point, the new μ initial population should be selected (between the $\mu+\lambda$ chromosomes). The "fitness function" was asigned a cost to all the individuals so the μ chromosomes with the lower cost are selected to create the new initial population.

The cost of each solution (Eq.1) is calculated with two terms: the penalization funcion Ψ asigns a very big cost if the difference between the nominal powers in the lines and the powers that flow across the lines is big. This does not mean that chromosomes that do not comply the power criterion can not be selected, if there are less than μ individuals that comply this criterion, the initial population is completed with chromosomes that do not meet it, but whose error is the smallest of it.

As the number of iterations grows, more chromosomes satisfy the criterion of powers, then the chromosomes that cause the least installed converters power, will be selected to create the new initial population, that is the first term of the fitness function.

V. Finalization of the algorithm

To end the algorithm, it is necessary to fulfil two conditions. First, more than μ chromosomes meets that with their injected power, all the powers in the lines are below their nominal value for all the possible situations. And second one, the difference between the total injected power of the best chromosome (this is the one whose installed power is lower), the average from all the installed powers of the chromosomes and the the total injected power of the worse chromosome (this is the one whose installed power is greater), is less than a certain value ε: Eq.5 and Eq.6.

$$\left| S_{T_{BestParent}} - \frac{1}{n}\sum S_{T_i} \right| \leq \varepsilon \tag{5}$$

$$\left| \frac{1}{n}\sum S_{T_i} - S_{T_{WhorseParent}} \right| \leq \varepsilon \tag{6}$$

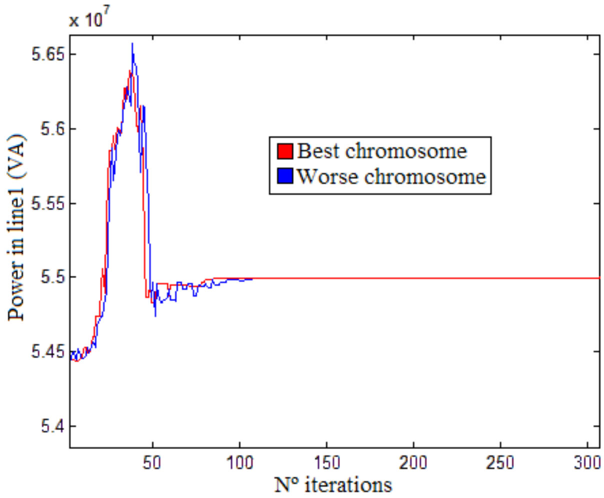
Using this approach ensures that if the algorithm is ending, is because it has found an overall minimum, and not a local one. At the first iterations the difference between those paremeters is very big, but as the algorithm is doing iterations that difference is decreasing.

And this structure is repeated for the posible five lines falls.

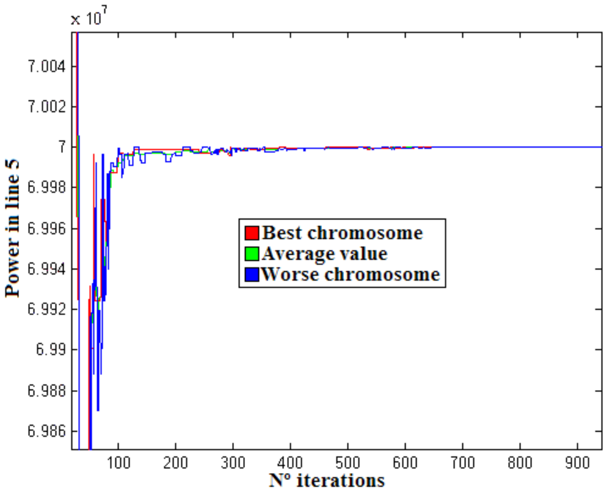
VI. Experimental results

This algorithm has been programmed in Matlab and its results have been validated with PsCad. After the algorithm is executed, the results of the bests chormosomes for the diferent cases, are represented in: Table IV, Table V, Table VI, Table VII and Table VIII.

Showing all the chromosomes parameters, only are necessary converters in case2 and in case5 (that is, when line 2 falls or when line 5 falls) because only the chromosomes impedances associated with this two cases have a significant value.



(a) Power flow across line1.



(b) Power flow across line5.

Figure 3: Evaluation of the algorithm in case2.

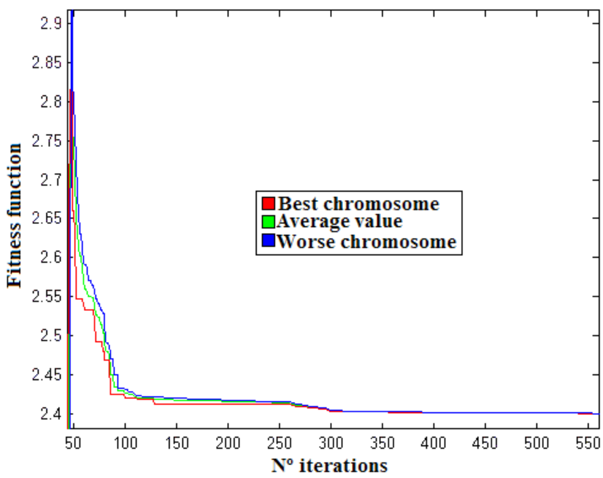


Figure 4: Fitness function evolution in case2.

Table IV: Best chromosome for case1.

	Line 1	Line 2	Line 3	Line 4	Line5
$\Delta X_i(\Omega)$	0	0	0	0	0
σ_i	0	3.15e-31	2.27e-29	6.38e-31	1.56e-31
$S_i(MVA)$	0	63.95	72.93	55.00	67.22
$S_{ci}(MVA)$	0	0	0	0	0

Table V: Best chromosome for case2.

	Line 1	Line 2	Line 3	Line 4	Line5
$\Delta X_i(\Omega)$	-0.0068	0	0	0.1205	0.0952
σ_i	3.14e-17	0	1.44e-14	1.02e-16	7.76e-18
$S_i(MVA)$	55.00	0	75.07	60.46	70.00
$S_{ci}(kVA)$	4.32	0	0	92.214	97.682

With the parameters of the best chormosome in case2, it is posible to conclude that there is necessary place three converters: one of 4.32 kVA per phase in line1 , other of 92.214 kVA per phase in line 4 and the last of 97.682 kVA in line 5 to ensures that no line is overloaded. Fig. 3 shows the power in the lines 1 and 5 for the best chromosome, the worse chromosome and the average value of all the chromosomes, versus the number of iterations. Is possible to see that with a small number of iterations the powers converge to their nominal value. Fig. 4 shows the evolution of the fitness function.

With the parameters of the best chormosome in case5, it is posible to conclude that there is necessary to place only one converter of 22.4 kVA per phase in line 1 to ensures that no line is overloaded, because the impedance and the power of the converters in the other lines are negligibled in comparison with the impedance and power of the converters in line 1. Fig. 5 shows the power in the line for the best chromosome, the worse chromosome and the average value of all the chromosomes, versus the number of iterations. Is possible to see that with a small number of iterations the power converge to its nominal value. Fig. 6 shows the evolution of the fitness function.

Table VI: Best chromosome for case3.

	Line 1	Line 2	Line 3	Line 4	Line5
$\Delta X_i(\Omega)$	0	0	0	0	0
σ_i	2.65e-23	1.96e-30	0	6.29e-29	1.10e-31
$S_i(MVA)$	35.80	45.68	0	59.06	48.06
$S_{ci}(kVA)$	0	0	0	0	0

Table VII: Best chromosome for case4.

	Line 1	Line 2	Line 3	Line 4	Line5
$\Delta X_i(\Omega)$	0	0	0	0	0
σ_i	2.19e-29	3.71e-29	6.53e-31	0	3.42e-30
$S_i(MVA)$	25.45	32.50	50.75	0	34.16
$S_{ci}(kVA)$	0	0	0	0	0

Table VIII: Best chromosome for case5.

	Line 1	Line 2	Line 3	Line 4	Line5
$\Delta X_i(\Omega)$	0.0354	8.1131e-7	-6.6601e-5	-3.0728e-8	0
σ_i	4.6063e-6	3.8839e-9	7.0730e-7	5.1670e-5	0
$S_i(MVA)$	55.00	71.241	6.99	59.045	0
$S_{ci}(VA)$	2.2400e4	0.8624	0.7030	0.0224	0

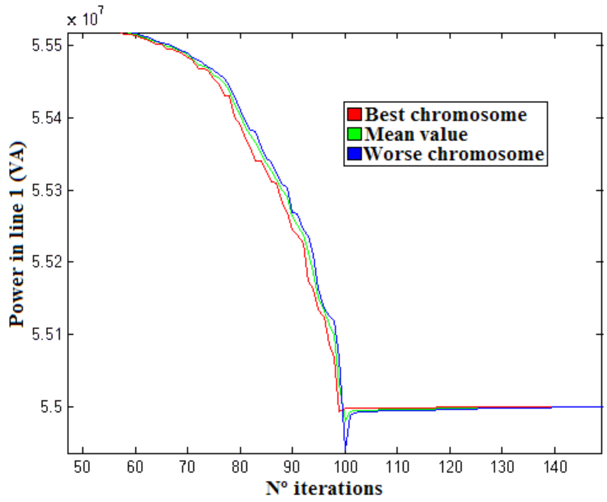


Figure 5: Power across line 1 in case5.

VII. Conclusions

This paper presents an evolutive algorithm for choosing the best placement for a series compensator in order to redistribute power flow under N-1 contigency. All the lines of the electric system can fall, but only one in each time. When line 2 or line 5 falls there are lines overloaded. To solve this problem the algorithm recommends to place series compensator in some lines in order to get new power flows with all the lines under their thermal limits. To solve all the possible situations it is necessary to place converters in lines 1,4 and 5, all the converters are bypassed until a fall appears.

Only is necessary the converters actuation if line 2 or line 5 falls, in the first case the converters placed in line 1, line 4 and line 5 must inject the necessary voltage to redistribute the power flow. In the second case, the converter placed in line 1 must start to inject the necessary voltage (different to the voltage in the other case), to redistribute the power flow too.

Besides, this algorithm finds a solution with a small number of iterations and with good convergence.

Acknowledgement

This work was supported by the Spanish Ministry of Education and Science under Project ENE2006-02930. The authors want to thank Red Electrica de España for the technical support.

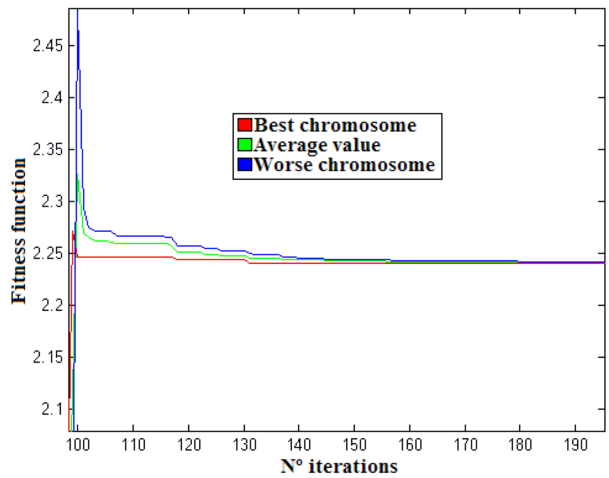


Figure 6: Fitness function evolution in case5.

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