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Genetic Algorithm approach in FACTS devices location for the improvement of energy efficiency in distribution networks

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***Abstract*—The paper deals with a genetic algorithm (GA) application in order to achieve an optimal location of FACTS devices in a distribution system. Using this optimization technique only the best individuals of a population are selected to create new possible solutions and these solutions are meant to improve the energy efficiency of the system. Two MATLAB programs are applied to a 33 bus test power system and results show the best suitable nodes to place FACTS devices.**

***Index Terms*—FACTS Devices, Genetic Algorithm, Energy Efficiency, Distribution Networks, Optimal Location.**

I. Introduction

The European Union ratified the Kyoto Protocol in May 2002 and committed to reduce emissions of six greenhouse gases. There are different aspects to be considered in order to reach this goal and one of them is energy efficiency in power systems. Energy efficiency can be improved along the power system and here the focus is set to the transmission and distribution network. Overall losses in a transmission and distribution system are considered normal in a range of 6% and 8%. There are different ways to achieve a better energy efficiency in distribution networks, such as high efficiency transformers and cables or applications like Flexible AC Transmission Systems (FACTS).

Considering different optimization techniques, Swarm Intelligence is an artifcial intelligence technique based on the study of the behavior of collective self-organized systems. Swarm Intelligence applied to power systems includes Ant Colonies Optimization (ACO), where artificial ants build solutions by moving on the problem graph and changing it so that future ants are capable of building better solutions. Problems such as losses minimization, reactive power compensation and system restoration have been solved using this kind of approach, as presented in [1, 2, 3, 4, 5]. In the same approach area lays Particle Swarm Optimization (PSO). PSO deals with problems in which the solution can be represented as a point in a n-dimensional space and improves its values sharing previous information found by the population. This technique is also employed in power systems to solve issues as load flow optimization [6, 7], reactive power control and planning [8], phase balancing [9] and economic dispatch [10, 11]. Another kind of heuristic method is the Artificial Neural Networks approach (ANN), inspired by neuronal systems and composed by units and their interconnections. After a special training ANN can perform predictions and this quality makes the approach especially suitable for system restoration and reconfiguration [12, 13, 14], faults detection [15] and power forecasting [16]. Moving to another technique, Evolutionary Algorithms also refer to a biological environment, considering the idea of evolution as a consequence of reproduction, mutation and crossover. They apply the principle of survival on a set of potential solutions and evaluate the goodness of a certain fitness function. Evolutionary Programming applied to power systems also considers power flow optimization [17, 18] and reactive power dispatch as studied in [19, 20]. Genetic Algorithms (GA) are also well employed to optimize [21, 22], plan reactive power [23, 24], evaluate system losses [25] and also to find the optimal location of FACTS devices [26].

The application of FACTS devices, employing a GA optimization technique, can actually improve energy efficiency in power systems. GA will be applied so that the location of FACTS devices and the reactive power considered are optimal. Here GA is applied to a power system of N_{bus} nodes to maximize energy efficiency (η). For each individual i out of the possible N, an array carries the values that represent the i-th individual: the node, N_{node}, the FACTS device reactive power Q_{facts} and the efficiency η_i. Two different MATLAB® programs are applied to the distribution network:

- A power flow program to evaluate the network's efficiency;
- A GA based program to optimize FACTS location and so improve energy efficiency.

These programs are meant to evaluate the evolution of network efficiency through the number of generations along with the best node/best reactive power evolution. The process sorts out individuals of the population considering their efficiency values and evaluates the stop criterion set for the problem. Later on, the algorithm applies the GA rules that are necessary to grow the population and in the final phase the algorithm outputs the best values reached for each generation.

II. Methodology

A. Genetic Algorithm

Genetic Algorithms were developed based on the evolutionary theories proposed by Darwin in the 19th century. These algorithms are based on the darwinian principle that the elements that are most suitable to their environment have the highest probability of surviving and they are able to transmit their characteristics to their offspring. A population of individuals evolves from generation to generation using mechanisms that can be compared to genetic reproduction and mutation. Natural evolution works on genetic material, that is the genotype of an individual: each alteration that improves the fitness of an individual emerges from the genetic heritage and natural selection promotes the reproduction of those individuals that enhance fitness qualities to the environment.
Reproduction is the core of the evolution process, since generational variations of a population are determined by genetic crossover and by random mutations that may occur. Reproduction sets the mix of genetic material from parents and this generates a quicker evolution compared to the one that would result if all descendants would contain only a copy of the genetic heritage from their parents. Evolution operates through cyclical and generational processes that are determined only by environmental issues and the interactions among different individuals. The possible solution of a certain problem is codified with a chromosome, through the definition of a bit string, whose genes are codified by 0 and 1. Individuals are evaluated through a function that measures their ability of problem solving and it identifies the most suitable to reproduction. The new population evolves based on random operators, using reproduction, mutation and crossover and the evolution exits the cycle when the stop criterion is reached.

B. Simulation Tool and Test Power System

The application of GA to a power system of N_{bus} nodes consists in creating a first population of N individuals, that represent possible solutions. This first step is considered to be the initialization of the problem. Figure 1 explains the process beyond the MATLAB® program that receives as input the system data and calls the power flow program. The individuals representative string is the number of node N_{node} and the FACTS device reactive power Q_{facts}. The values from the first population are introduced in the test system and a power flow algorithm is run in order to evaluate the fitness function, here chosen as the system efficiency, represented by η. The stop criterion is set to be the number of maximum generations considered along the process, N_{gen} and until the stop criterion is not reached, the values obtained with the power flow algorithm are sorted considering the individuals that collect the best result in the population. That is, a number of best individuals is set, N_{best}, and the mating operation is performed among them, since these individuals are those who passed the competitive selection and are the most likely suitable to build a new generation. After the mating couples are decided, genetic operators are applied in order to obtain new solutions. Genetic operators are mutation and crossover and the possibility for a node to inherit the DNA from father or mother node is set through the variable α that takes random values between 0 and 1. The new generation node will undergo mutation and crossover depending on the values of α. These new solutions are reintroduced in the system and again all individuals are evaluated through the fitness function.

III. Simulation Results

The algorithm is applied to a 33 bus radial distribution system using data presented in [27] and figure 2 represents a sketch of the network under study. The simulation is set for a number of generation N_{gen} and the maximum number of best individuals is set to be N_{best}. These individuals are the new genitors of the new population and in order to establish the individuals ranking, system efficiency is evaluated through the power flow program. For each new population the first 3 individuals with the best efficiency are chosen to reproduce and their behavior is implemented considering their probability of reproducing, including also crossover and mutation. Simulations are performed considering FACTS located at 6 different nodes. The original FACTS location and Reactive Power are presented in table I.

Node	Q
2	-0.5
3	0
9	1
13	-1
18	-0.9
5	1

Table I: Original data

The end of the iterations leaves a final matrix, represented in Table II where each node is associated to the number of generation and the best efficiency value.

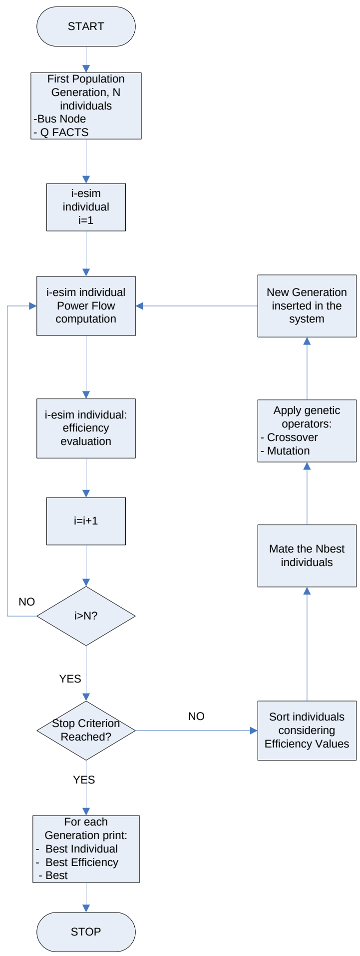

Figure 1: Flow chart

Generation	Best Node	Q	Efficiency
1	9	1	0,93506467
2	9	1	0,93506467
3	9	1	0,93506467
4	9	1	0,93506467
5	9	1	0,93506467
6	9	1,00188167	0,93506818
7	9	1,0138386	0,93508957
8	6	1,02229476	0,93582271
9	6	1,02229476	0,93582271
10	6	1,02229476	0,93582271
11	7	1,0281536	0,93589906
12	6	1,04554765	0,93594331
13	6	1,04554765	0,93594331
14	6	1,04554765	0,93594331
15	6	1,04554765	0,93594331
16	6	1,04848281	0,93595831
17	6	1,04848281	0,93595831
18	33	1,07769911	0,93790722
19	33	1,05354071	0,93793153
20	33	1,01840826	0,93794712
21	33	1,00743763	0,93794716
22	33	1,00743763	0,93794716
23	33	1,00743763	0,93794716
24	30	1,07544044	0,94013945
25	30	1,07544044	0,94013945
26	30	1,07544044	0,94013945
27	30	1,07544044	0,94013945
28	30	1,07544044	0,94013945
29	30	1,07544044	0,94013945
30	30	1,07544044	0,94013945
31	30	1,07544044	0,94013945
32	30	1,07544044	0,94013945
33	30	1,0763657	0,94014269
34	30	1,08830733	0,94018328
35	30	1,08830733	0,94018328
36	30	1,08830733	0,94018328
37	30	1,08830733	0,94018328
38	30	1,08830733	0,94018328
39	30	1,10121093	0,94022475
40	30	1,10121093	0,94022475
41	30	1,10838617	0,94024675
42	30	1,1125604	0,94025919
43	30	1,12064538	0,94028257
44	30	1,12530388	0,94029559
45	30	1,12530388	0,94029559
46	30	1,12530388	0,94029559
47	30	1,12530388	0,94029559
48	30	1,12530388	0,94029559
49	30	1,12530388	0,94029559
50	30	1,13009804	0,94030867

Table II: Final data

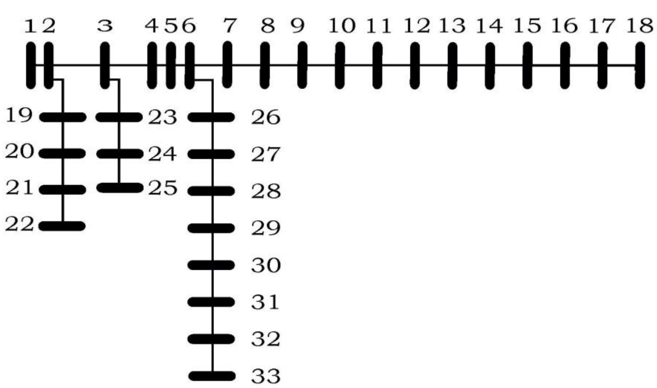

Figure 2: 33 Bus distribution system

Figure 3 shows the evolution of the efficiency through the number of generations and also the evolution to the best node with the best reactive power input.

IV. Conclusions

For this specific study the results obtained show which is the best node to be chosen in order to obtain an optimal location of FACTS. The best efficiency is obtained placing the FACTS device in the node indicated in table II and figure 3. The results given show how the efficiency varies considering different nodes as best candidates and that the final result not only gives the best efficiency score, but is also a quite stable result throughout the simulation time. Given reactive power data of FACTS, in a rather simple and quick way it is possible to

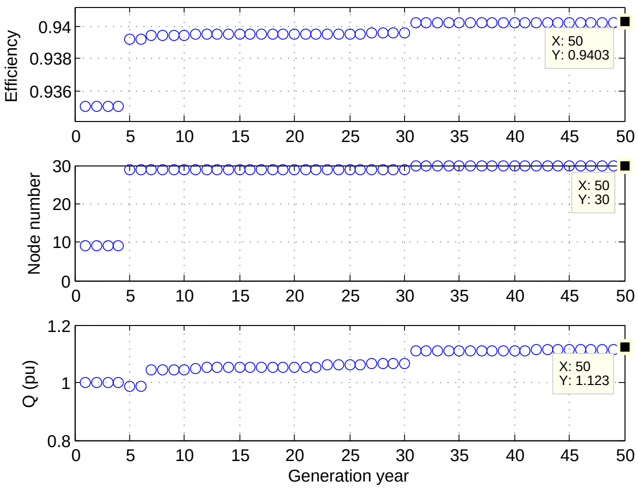

Figure 3: Efficiency Evolution

decide which nodes are the best suitable to place these kind of devices. It is important to mention that as a consequence of using a random function to generate the value of α, the results may vary for each run of the program.

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