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 artificial 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 Nbus nodes to

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maximize energy efficiency ($\eta$). 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 $Q_{\text{facts}}$ and the efficiency $\eta_i$. Two different MATLAB®
programs are applied to the distribution network:

- A power flow program to evaluate the network’s effi-
ciency;
- 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 algo-
rithms 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 $Q_{\text{facts}}$. 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
$\eta$. 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 $\alpha$ that takes random
values between 0 and 1. The new generation node will undergo
mutation and crossover depending on the values of $\alpha$. 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 per-
formed considering FACTS located at 6 different nodes. The
original FACTS location and Reactive Power are presented in
Table I.

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<tr>
<th>Node</th>
<th>$Q$</th>
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<tr>
<td>3</td>
<td>0</td>
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<tr>
<td>9</td>
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<td>-0.9</td>
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<td>5</td>
<td>1</td>
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</table>

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.
First Population Generation, N individuals

Bus Node

FACTS

i-esim individual: efficiency evaluation

Stop Criterion Reached?

Sort individuals considering Efficiency Values

Apply genetic operators:
- Crossover
- Mutation

For each Generation print:
- Best Individual
- Best Efficiency

STOP

NO

YES

STOP

Figure 1: Flow chart

Figure 2: 33 Bus distribution system

Table II: Final data

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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
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 $\alpha$, the results may vary for each run of the program.

REFERENCES


