OPTIMAL PLACEMENT OF FACTS UNITS FOR MINIMIZING THE IMPACT OF VOLTAGE SAGS IN POWER NETWORKS WITH HIGH WIND ENERGY PENETRATION

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ABSTRACT
This paper presents a methodology for the optimal placement of wind farms and FACTS units in power networks, in order to guarantee the voltage profile and to maximize the loadability of the system under voltage sags conditions. Results shown in the paper indicate that the proposed formulations can be used to determine which the best buses are where the addition of Var sources can enhance the voltage stability of the whole network.

INTRODUCTION
In recent years, there has been an increasing interest in the production of electric energy from renewable energy sources. By 2020, it is expected that the total wind power generation will supply around 12% of the total world electricity demands. However, integration of such wind resources into power system grids presents still some major challenges to power system operators and planners. The more critical aspects are the fault ride-through capability of wind farms and the voltage stability of the power network.

Electric power planning with the presence of high wind energy requires the definition of several factors, such as: the best technology to be used, the number and capacity, the best location or the grounding connection. The installation of STATCOM, SVC or DVR units at optimal places can result in an improvement of voltage stability and a reduction of system losses.

The selection of the best places for installing FACTS in large distribution system is a complex combinatorial problem. Recently, Distributors Operators have successfully applied metaheuristics optimization methods for planning issues. Among the advantages of using it, are the capability to provide a satisfactory solution of the problem, the low computational complexity and the speed to reach the solution. The use of Genetic Algorithms (GA) in power systems planning is gaining popularity, not only due to the robustness of the method, but also to the possibility to find the global optimal solution in complex multi-dimensional search spaces [1].

OBJECTIVE
The objective of this analysis is to find the best allocation of different FACTS systems in order to maximize loadability of the system and improve voltage stability after fault situations using heuristic methods. The methodology is based on the application of the two following processes:
- An automatic method for optimal allocation of wind and FACTS units on distribution network. The aim of this method is to maximize loadability conditions of the system and to provide potential candidates to the problem solution. For this task GA are used to evaluate possible solution of the optimization problem.
- A method for evaluating the impact of wind farm and FACTS units installation on voltage profile and voltage stability after voltage sags on the distribution network.

Figure 1 shows a flowchart of the optimization problem.

VOLTAGE STABILITY
Voltage Stability is defined as the ability of a power system to maintain steady-state voltage at all buses in the system.
after being subjected to a disturbance from a given initial operating condition [2]. In the literature, two voltage stability problems are analysed:
- Estimation of the maximum loadability.
- Computation of the critical power system loading that could lead to voltage collapse.

Voltage stability is usually represented by P-V curve (Fig. 2). In this figure the noise point is called the point of voltage collapse (PoVC) or equilibrium point. At this point, voltage drops rapidly with an increase of the power load and subsequently, the power flow Jacobean matrix becomes singular. Classical power-flow methods fail to converge beyond this limit. This failure is considered as an indication of voltage instability and frequently associated with a saddle-node bifurcation point.

Although voltage instability is a local phenomenon, the problem of voltage stability concerns to the whole power system, becoming essential for its operation and control. This aspect is more critical in power networks, which are heavily loaded, faulted, or with insufficient reactive power supply.

- The system is balanced.
- The active and reactive powers consider only the fundamental frequency component.
- The size of Var source is treated as a continuous variable.
- The reactive capability of a generator is portrayed by the conventional PQ diagram.

It should be emphasized that the methodology proposed in this paper can be directly applied to locate any type of FACTS devices. In this paper, for the sake of simplicity only the placement of SVCs is considered.

**GENETIC ALGORITHM**

Genetic algorithms (GA) are a family of computational optimization models invented by Goldberg (1989) and Hopgood (2001). GA [3] has been used for solving both constrained and unconstrained optimization problems modelled on a natural evolution process. It drives to the biological selection, where the operators employed are inspired by the natural evolution process. The GA method modifies a population of individual solutions on each step (generation) of the algorithm according to genetic operators. The main advantages of GA over conventional optimization methods are:
- They do not need any prior knowledge, space limitations, or special properties of the objective function about the problem to be optimised.
- They do not deal directly with the parameters of the problem. They only require codes, which represent the parameters and the evaluation of the fitness function to assign a quality value to every solution produced.
- They work with a set of solutions from one generation to the next, making the process likely to converge to a global minimum.
- The solutions obtained are randomly based on the probability rate of the genetic operators such as mutation and crossover.

This technique is very useful for solving optimization problems, such as the proposed in this paper, which consists on searching the best allocation of FACTS units in distribution networks with wind energy in order to alleviate the voltage profile and to maximize the loadability of a power network. The optimisation problem is formulated as:

\[
\text{Min } F(x) \\
\text{Subject to:} \\
A_{\text{eq}}(x) = B_{\text{eq}} \\
A(x) \leq B_{\text{eq}} \\
x \in S
\]

Where:
- \( F(x) \) is the objective function to be optimised
- \( A_{\text{eq}} \) is equality constraints
- \( A \) is inequality constraints
- \( x \) is the vector of variables
- \( S \) is the search space.

In power networks with huge amount of wind penetration levels, the role of voltage stability is of great importance due to the lack of reactive power contribution of many Wind generators as well as their integration into weak networks.

**REACTIVE POWER PLANNING**

The use of FACTS devices in power networks with wind generation, make the application of a large amount of Var compensation more efficient. To determine the optimal location of reactive power compensators, two key aspects must be taken into account by planners and manufacturers: the right location and size of the device. Up to now, locations of Var sources were computed by estimation or by approach; however, neither of both methods are effective.

Traditionally, the Reactive Power Planning (RPP) methodology is based on the definition of complex objective functions and network constrains, and on the use of optimization algorithms. In this paper, the following assumptions are considered while formulating the Var planning problem:
OPTIMIZATION METHODOLOGY FOR OPTIMAL ALLOCATION AND REACTIVE POWER PLANNING

Encoding
In this paper, value encoding of chromosomes has been used where the placement problem is modelled by using real numbers. Each chromosome has seven genes that represent the variables of the system. The first one represents the loadability parameter of the system ($\lambda$); the other ones represent the bus number location at which wind units could be connected and the size of Var injection from the SVC unit.

Fitness Function
The Fitness Function (FF) assigns a goodness value for each individual of the population and is used for driving the evolution process. In the case of GA, this calculation must be automatic, and the development of a procedure for computing the quality of the solution must be solved. In this paper, to consider the load change scenarios, PD and QD can be modified as:

$$PD(\lambda) = PD_0 (1 + \lambda K)$$
$$QD(\lambda) = QD_0 (1 + \lambda K)$$

Where:
- $PD_0$ and $QD_0$ are the original power load (base case).
- $K$ is a multiplier designating the rate of load change.
- $\lambda$ represents the load parameter.

The knee point of load characteristics (Fig. 2) defines the critical loading value of the system ($\lambda = \lambda_{critical}$). A load increase beyond this limit will result in a voltage constraint violation and the system would no longer operate.

To maximize the loadability of the system through the load parameter $\lambda$, the FF function used is:

$$FF(x) = \lambda$$

Where:
- $x$ is a vector of variables: load parameter, bus connection and VAr injection.
- $\lambda$ value depends on voltage constraints violation.

Constraints
The main constraints considered in the optimization process are the following:
- Voltage level at all buses should be held within established limits.
- Active and reactive power generation is limited by the generator capabilities.

Optimisation Formulation
According to the fitness function objective and constraints equations, the optimization problem can be formulated as:

Min $F(x) = 1 - FF(x)$

Subject to:

$$U_{min} \leq U_i \leq U_{max} \quad n=1,2,\ldots,N$$
$$P_{gmin} \leq P_g^k \leq P_{gmax} \quad k=1,2,\ldots,K$$
$$Q_{gmin} \leq Q_g^k \leq Q_{gmax} \quad k=1,2,\ldots,K$$

CASE STUDIED
In this section, the proposed GA has been applied to a distribution network such as the modified IEEE 34 node test feeder [4]. Two different situations have been considered.

Optimal allocation of SVC units in networks with wind farms
Initially (base case), there are not any wind unit connected to the distribution network (Fig. 3). The GA will indicate the optimal allocations of several SVC units which have been computed in consecutive iterations steps at different wind farm penetration levels.

Figure 4 and 5 show the voltage profile and maximum loadability voltage profile of the case studied at the base case and after the application of the optimisation algorithm.

Three wind energy penetration scenarios are considered. On each scenario, optimal allocations of SVCs are computed by the GA.

Table I shows the results obtained by the algorithm; the bus number where each SVC unit is located, the reactive power injected by the SVC and the maximum loadability for low limit operational voltage ($\lambda_{max}$).
It is shown that optimal location of SVC units in distribution networks with wind generation enhance the voltage profile and increase the maximum loading of the system. In the particular case of adding three wind farms and SVC units connected to the power network the maximum loading of the system for operational voltage limit is increased 74% (Fig. 6).

In order to prove the GA results suitability under voltage sag situations, the modified IEEE-34 bus power network with three wind farms and three SVC units optimally located at buses number: 10, 23 and 26 has been simulated in PSS/E [5]. A three-phase fault is simulated at bus # 9, producing a voltage sag depth of 80% with 0.5s voltage sag duration. In Fig.7, it can be seen how the installation of optimally located SVC units increases the fault ride through capability of the wind turbines under voltage sag situations.

CONCLUSIONS

In this paper, a method based on GA for optimal placement of FACTS has been successfully developed to maximize the loadability of the system and to improve the fault-ride through capability of wind turbines under voltage sag situations. GA has been tested in distribution networks and it has been proved its ability to reach the global optimal solution for the allocation of VAr compensation units in distribution networks with wind generation.

REFERENCES


Faults and voltage sag situations

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