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A multiobjective approach for reactive power planning in networks with wind power generation

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ABSTRACT

The increase in wind energy penetration is creating a wide range of technical problems in power networks. Reactive Power Planning is one of these crucial issues which entails all the necessary planning actions to improve the voltage profile as well as the voltage stability in power networks. On the whole, the ultimate aim in reactive power planning could be addressed as the resolution of an optimization problem, in which multiobjective optimization techniques emerge as good alternatives to fulfil several goals simultaneously.

Among all these techniques above mentioned, genetic algorithms stand out because of their speed of calculation and simplicity. An existing 140-bus power system is used to validate the performance and effectiveness of the proposed method where several wind farms and FACTS units are optimally located.

1. Introduction

Nowadays, there are several EU Directives pursuing the public goal of sustainable electricity in European member states and promoting the further development of electricity production from renewable energy sources by means of safe and reliable system operations. Among all, wind energy has proved to be one of the most competitive and efficient renewable energy sources and, as a result, its application is indeed continuously increasing. The fact that a huge amount of wind energy is collapsing power networks has forced Independent System Operators (ISO) to use new operating strategies which, however, are not currently available. One of the most critical issues of the challenging situation above defined is the Reactive Power Management, which entails the requested operation as well as all the planning actions to be implemented in order to improve both, the voltage profile and the voltage stability in power networks [1].

Reactive Power Management involves the definition of both, the reactive power planning of var sources and the reactive power dispatch of the already installed reactive sources. Traditionally, Reactive Power Planning has been formulated as an optimization problem where the determination of the instantaneous “optimal” steady state of an electric power system is solved by an Optimal Power Flow algorithm (OPF) [2]. In general, the optimization problem is defined as a single objective function expressed as a mathematical function based on some criteria. In many cases, the main objective is the minimization of the fuel cost function and/or system losses. Nevertheless, not only the cost optimization should be aimed at this formulation, since a power planning designer or decision maker needs to arrive to a determination handling contrasting and, in some situations, conflicting design objectives.

At this point, the use of a multiobjective optimization algorithm stands out as the only suitable way to design and to optimally locate reactive power injection units in power networks and, at the same time, to consider a wide range of objectives functions such as: improving the voltage stability, reducing active power losses or minimizing the cost of shunt reactive power sources.

Compared with single objective optimization techniques, the multiobjective ones offer advantages because they are able to produce a solution containing different trade-offs among different individual objectives and this enables the ISO to select the best final solution.

When performing Reactive Power Management studies in power networks with wind energy penetration, it should be taken into account that variable speed wind turbines are connected to the grid by electronic power converters and therefore they are capable to offer great reactive power flexibility in the interface to the grid.

In spite of this, power system operators are not presently making full use of the available reactive capability offered by wind

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farms and, as a result of this inefficient management, power networks with huge amount of wind energy are facing problems related to voltage stability or voltage collapse [3,4].

Lately, and in an attempt to fill the existing gap, Flexible AC Transmission Systems (FACTS) devices have emerged as a feasible option to improve voltage stability by influencing power flows and improving voltage profiles [5]. The optimum usage of these devices implies to find out the optimal location in which their influence would be more useful, as well as to determinate their optimum sizing.

The objective of the paper is to develop a Multiobjective Reactive Power Planning Strategy for the coordinated handling of reactive power from FACTS devices and wind farms. The optimization methodology is based on genetic algorithms and includes, directly in its formulation, the reactive power capabilities of the DFIG variable speed wind farms and the real physical limits of the SVC. In the existing literature, wind farms are usually considered as PV or PQ nodes for load flow or reactive power studies [6]. Thus far, there have been no many pieces of work focused on including the reactive power capability of the DFIG turbines directly in the optimization formulation as it is proposed in this paper. In the case of Static var Compensator, they are usually represented in power flow analysis as a variable reactance [7]. However, that representation is not completely right because it does not take into account the available physical limits of the SVC for the reactive power injection. In this paper, SVC's models are included in the optimization process considering the physical limits of the thyristor firing delay angle for computing the reactive power injection.

The proposed methodology will aid power system operators to determine which is the optimal placement to locate wind farms and FACTS devices in power networks and which is the amount of reactive power that should be injected in the network to improve simultaneously the voltage stability, to reduce active power losses as well as to reduce the cost of the var injection sources. Furthermore, the proposed optimization algorithm is able not only to handle the multiobjective goals simultaneously but also to cope with the variable load power demand and variable wind power production.

The proposed optimization formulation in the paper focuses on Static Var Compensator (SVC) and Double-Fed Induction Generators (DFIGs) variable speed wind turbines. However, it should be emphasized that this developed method could be applied to any other controllable FACTS devices too, such as STATCOM or any other variable speed wind turbine such as a full power converter. Moreover, any other objective function could be included in the multiobjective algorithm.

The content of the paper is organized as follows: Section 2 analyses the Reactive Power Capabilities from wind farms. In Section 3 the Reactive Power Planning Optimization Strategy is described in which the available power capability from wind turbines has been included. A description of the Multiobjective Genetic Algorithm is shown in Section 4. The methodology proposed in the paper is applied in an existing 140-bus power system in which several wind farms and SVC devices are optimally located. Results of this methodology are shown in Section 5. Concluding remarks are presented in Section 6.

2. Reactive power injection from wind turbines

Traditionally, wind farms have been represented as PV or PQ models in power flow studies [6]. The methodology implemented till now seems to be quite simple; however it presents the main drawback that the available reactive power range is limited either to a maximum cos (φ) or to a fixed regulation band. Additionally, this representation is not completely accurate and therefore does not allow taking full advantage of the reactive power injection from the wind turbine.

In this paper, a better wind turbine model is proposed that indeed takes into account the current available reactive power capability for each working operation point. The proposed formulation could be included thus in any modified power flow analysis for optimum reactive power planning.

2.1. Reactive power injection from fixed speed wind farms

Fixed speed wind generation plants have not the capability to provide a dynamic reactive power support to the network. Facing this situation, it is necessary to connect static reactive power sources or FACTS devices at wind turbine terminals. Supplied reactive power injection from static reactive power sources such as shunt bank capacitors depends on the voltage level at the connection point and therefore may be not sufficient under low voltage situations. Moreover, capacitors banks are not able to provide a continuous reactive power injection. In contrast with this inefficient situation, FACTS devices such as Static Var Compensator (SVC) could be controlled in order to provide dynamic reactive power support to the network [8] something that static devices like capacitors are not able to match.

A Static Var Compensator (SVC) is defined as a device whose output is adjusted to exchange capacitive or inductive current in order to maintain or to control specific parameters of the electrical power system. In this paper, the considered SVC corresponds to a TCR (Thyristor Controlled Reactor) as shown in Fig. 1

In this situation, injected steady-state current [9] is expressed thus:

$$I = \begin{cases} \dfrac{U}{X_L}(\cos\alpha_{svc} - \cos\omega t), & \alpha_{svc} \le \omega t < \alpha_{svc} + \sigma \\ 0, & \alpha_{svc} + \sigma \le \omega t < \alpha_{svc} + \pi \end{cases} . \tag{1}$$

where: U voltage at SVC connection point, it is the voltage that it is being controlled, X_L total inductance, X_c capacitor, α_{svc} is the firing delay angle, σ is defined as the SVC conduction angle according to:

$$\sigma = 2(\pi - \alpha_{svc}) \tag{2}$$

According to Fourier analysis [9] the variable susceptance, B_{svc}, could be expressed as:

$$B_{svc}(\alpha_{svc}) = \frac{2\pi - \alpha_{svc} + \sin 2\alpha_{svc}}{\pi X_L} \tag{3}$$

Many research studies represent the SVC as a variable reactance taking into account the reactive power and the voltage limits at the connection point [10]. However, this representation is not fully

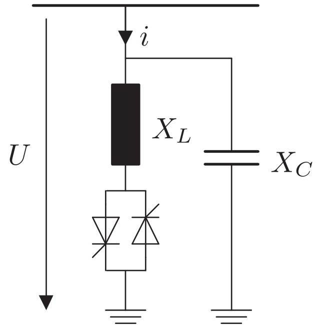

Fig. 1. Static Var Compensator diagram.