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The Impact of Active Power Losses on the Wind Energy Exploitation of the North Sea

Hossein Farahmand[a]*, Leif Warland[a], Daniel Huertas-Hernando[a]

[a] SINTEF Energy Research, Sem Sælands vei 11,P.O.Box 4761 Sluppen,7465 Trondheim, Norway

Abstract

Transmission active power losses can influence the distribution of power flows in the transmission grid which consequently alter the generation dispatch and scheduling through the power system. This can especially affect the exploitation of large scale renewable energy sources (RES) since they are normally installed far away from load centres. RES technologies are expected to cover a large portion of the future energy mix in the continental European power system and grid bottlenecks are a critical factor for successful integration of RES technologies in Europe. In this respect, transmission losses can significantly affect the potential grid bottlenecks and the exploitation of the expected energy produced by RES.

In this paper a comparison analysis is carried out on approaches to include active power losses in a DC optimal power flow. The initial idea is to apply a method to the existing flow-based market model Power System Simulation Tool (PSST), a tool for studying the effect of high penetration of wind power and consequent grid expansion in the European power system. Implementation of losses in large scale power systems significantly increases the computational burden. A solution to reduce computational time is to calculate reasonably good approximations of the active power losses. This paper proposes an approach to include transmission active power losses that can be implemented in large scale power system in reasonable computational time.

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Keywords: Transmission active power losses; DC-optimal power flow; Linearized loss approximation; Offshore wind production; power generation dispatch

Nomenclature

NG	number of generators
NB	number of busses

* Corresponding author. Tel.: +47-930-06538; fax: +47-735-97250.
E-mail address: Hossein.Farahmand@sintef.no

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C_i	generation cost at Bus i (EUR/MWh)
G_i	generation dispatch at Bus i (MWh)
D_i	demand at Bus i (MWh)
θ_i, θ_j	voltage angles at Buses i and j, respectively (radian)
D_i	demand at Bus i (MWh)
B_{ij}	susceptance of transmission line ij (Ω^{-1})
$\underline{G_i}, \overline{G_i}$	maximum and minimum generation output at Bus i (MW)
$\overline{P_{Lij}}$	active power loss on transmission line ij (MWh)
I_{Lij}	current on transmission line ij (A)
r_{ij}	resistance of transmission line ij (Ω)
x_{ij}	reactance of transmission line ij (Ω)

1. Introduction

The increased integration of wind power, both onshore and offshore, and the demand for improved power system operation give rise to a growing need for transnational power exchanges [1]. In this paper, a comparison study has been carried out between different methodologies which calculate active power losses in power system analysis. Focus is the impact of power losses on the exploitation of the wind energy potential in the North Sea [2].

The inclusion of losses effectively changes both the total generation cost and the optimal generation dispatch as compared to the lossless situation. The active power losses can influence the distribution of power flows along transmission lines and energy mix throughout power systems. Therefore, the losses can especially affect the exploitation of potential energy produced by large scale RES, since they are usually located far away from load centers. This is the main motivation for including losses in this study. Ideally, AC optimal power flow (OPF) should be used to calculate power flow and active power losses in the transmission system. However, AC optimal power flow is nonlinear optimization problem which requires extensive computational effort when solving large scale power systems. A solution to reduce computational burden is to calculate reasonably good approximation of the active power losses [3]. Thus, trade-off between the computational time and the accuracy of the results is necessary.

The AC power flow equations can be approximated by set of linear DC power flow. DC power flow represents a reasonably accurate approximation of AC power flow [4]. DC power flow equations retain the convexity of optimization problems and can be embedded in optimal power flow calculation. The major advantage of DC optimal power flow models is the possibility of obtaining solutions fast and without using iterative processes. These features are of great value when such models are applied to large scale systems where the OPF problem needs to be solved under various operating conditions and several times. However, DC power flow models do not account for active power losses. The challenge arises when: *i)* trying to keep computational effort within reasonable time; *ii)* accurately model active power losses. This paper presents a methodology to include active power losses in DC optimal power flow calculation that can be implemented in large scale power system with reasonable computational time.

This paper is organized as follows. Section 2 introduces the DC-OPF problem. Approaches to include transmission power losses into DC-OPF problems are outlined in Section 3. The simulation toolbox to implement the approaches proposed in the previous section presented in Section 4. Subsequently, the approaches are tested on benchmark IEEE test system and their performance are assessed and discussed in Section 5. Moreover, the approaches are applied on Northern European power system, as example of a relevant large scale system where impacts of transmission losses are discussed in relation with offshore wind and interconnection utilization. Section 6 concludes the paper.

2. DC OPF model

Fig. 1 shows a two-bus system, and equivalent circuit of a transmission line, between bus i and bus j with a lumped parameter represented by the series impedance Z_{ij}. The major approximation in a DC power flow is to neglect reactive power and transmission line resistance, as well as the assumption of a flat voltage profile at all