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Impact of TCSC Installation on ATC in a System Incorporating Wind and Hydro Generations

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Abstract

This paper examines the impact of installing Thyristor Controlled Series Compensator (TCSC) on Available Transfer Capability (ATC) in a system with wind and hydro generations. Wind resource is modelled as an active power generation, wind power being decided by average wind velocity values over 24 hour duration. Hydro power output is represented as a polynomial in two variables, water discharge and volume of water in the reservoir. The variation in ATC is first observed with varying wind and hydro generations over 24 hours and then a steady state model for TCSC is used to bring out its effect on ATC. The ATC values with TCSC are obtained by varying the location of the device through different lines. The site which gives the maximum values for ATC is chosen as the optimal placement of TCSC. Modified IEEE 24 bus reliability test system (RTS) is used for the study.

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Keywords: Optimal Power flow; TCSC; ATC; bilateral transactions; water discharge

Nomenclature

Sets	
x, u, p, ξwind, ξhydro ξTCSC, N, N_k, T	Denote state vector, control parameters, fixed parameters, parameters for wind, hydro and TCSC, no. of buses, hydro units, set of time intervals respectively.
Index variables	

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i, j, k, t	Represent the indices for buses, hydro units and time intervals respectively.
Variables & parameters	
λ	Loadability factor
P_{Gi}, P_{Wi}, P_{Hi}	Denote the active power generation for thermal, wind and hydro generators at i^{th} bus.
Q_{Gi}	Represents the reactive power generation for thermal unit at i^{th} bus.
P_{Di}, Q_{Di}	Are the active and reactive power demands at the ith bus.
$V_i, V_j, \delta_i, \delta_j$	Are the voltages and voltage angles at buses i and j respectively.
$P_{Gi\,min}, P_{Hi\,min}, P_{ij\,min}$ $P_{Gi\,max}, P_{Hi\,max}, P_{ij\,max}$	Represent the minimum and maximum limits of thermal generation, hydro generation power flows for active power.
$Q_{Gi\,min}, Q_{ij\,min},$ $Q_{Gi\,max}, Q_{ij\,max}$	Represent the minimum and maximum limits for thermal generation and power flows considering reactive power.
$V_{i\,min}, V_{j\,min}$ $V_{i\,max}, V_{j\,max}$ $\delta_{i\,min}, \delta_{j\,min}$ $\delta_{i\,max}, \delta_{j\,max}$	Denote the minimum and maximum values for voltage and voltage angles at buses i and j.
P^o_{Gm}, P^o_{Dn}	Are the generation and demand values at seller and buyer buses.
P_{Gm}, P_{Dn}	Denote the change in generation and demand at seller and buyer buses respectively.
X_{ij}, X_c, X_{ijeff}	Represent the reactance of transmission line between buses i and j, the reactance of TCSC and the equivalent reactance of the transmission line after the installation of TCSC.
$y_{ijeff}, g_{ijeff}, b_{ijeff}$	Denote the effective values of transmission line admittance, conductance and susceptance after the installation of TCSC.
G_{ijeff}, B_{ijeff}	Represent the effective values of conductance and susceptance matrices after TCSC installation.
v_{ci}, v_r, v_{co}, P_r	Are the cut-in speed, rated speed, cut-out speed and rated power outputs of wind turbine.
$c_{1k}, c_{2k}, c_{3k}, c_{4k}, c_{4k}, c_{5k}$	Denote the coefficients of hydro power generation for k^{th} hydro plant.
q_{Hk}, Vl_{Hk}	Represent the discharge and volume of water in the reservoir for k^{th} hydro unit.
I_{Hk}, S_{Hk}	Denote water inflows and spillage respectively for k^{th} hydro unit.
$Vl^{min}_{Hk}, Vl^{max}_{Hk}$	Are the minimum and maximum limits of water level in the reservoir for k^{th} hydro unit.
$q^{min}_{Hk}, q^{max}_{Hk}$	Denote the lower and upper limits of water discharge from the reservoir for k^{th} hydro unit.
$Vl^{begin}_{Hk}, Vl^{end}_{Hk}$	Represent the initial and final water levels in the reservoir for k^{th} hydro unit.

1. Introduction

The NERC report [1] quotes, "ATC is a measure of transfer capability remaining in a physical transmission network for further commercial activity over and above the committed uses." ATC calculation in a restructured market has been taken up by many authors. ATC determination with FACTS devices using PTDFS approach is presented in [2]. [3] presents ATC calculation with ZIP load model.

TCSC models for improvement of ATC are formulated in [4]-[6]. ATC calculation with renewable energy resources is the current area of interest for various researchers. In [7] ATC is determined incorporating wind generation. Available transfer capability calculation with large offshore wind farms connected by VSC-HVDC is presented in [8]. In [9] an assessment of transfer capability requirement for wind power generation using combined deterministic and probabilistic approach is put forth. An optimal power flow solution incorporating wind power is given in [10]. ATC calculation with hydro generation has not been considered by many authors but a number of authors have considered hydro generation for optimal hydrothermal coordination problem. A model for optimal scheduling of hydro thermal systems including pumped storage and wind power is given in [11]. Short-term optimal hydrothermal scheduling problem is considered in [12], [13]. In [14] an optimized day-ahead hydrothermal wind energy systems scheduling using parallel PSO is presented.

In this paper an optimal power flow (OPF) based approach [15]-[19] is used for bringing out the impact of TCSC on ATC in a system with wind and hydro generations. Rest of the paper is organized into 6 sections. Section 2