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Improvement of economic profit by optimal allocation of TCSC & UPFC with wind power generators in double auction competitive power market

Subhojit Dawn *, Prashant Kumar Tiwari

Department of Electrical Engineering, National Institute of Technology (NIT), Silchar, Assam, India

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A B S T R A C T

This paper presents a simple and reliable optimization approach to optimally allocate the Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) with wind generator under deregulated power system. The proposed approach is based on step by step variation in control parameters of TCSC and UPFC devices. Results have been determined for all possible locations, compensation level and reactance of TCSC & UPFC, reactive power injection or absorption, maximization of social welfare, maximization of profit with minimization of objective function. The double auction bidding model has been incorporated in this paper. The impacts on the locational marginal pricing and system voltage have been also investigated in this work. The effectiveness of the proposed approach for optimal placement of TCSC and UPFC has been tested and analyzed on modified IEEE 14-bus and modified IEEE 118-bus systems.

Introduction

In recent years, due to the mounting demand for energy and increasing population of the world switching from non-renewable energy sources to renewable energy sources is not an option, it is a necessity. People choose to use wind energy for environmental, financial, independence, reliability and social reasons. Our energy choices have a huge impact on our environment. More than 50% of the electricity used in India is generated by burning of coal in thermal power stations. This coal is resourced by strip mining, shaft mining, pit mining and mountain top removal. All of these methods of extraction and the burning of coal have a deleterious effect on the water, ground and air, not to mention the health of workers and nearby residents. Natural gas and nuclear energy are other major sources of producing electricity nationally but the extraction of energy is risky as well as it causes severe damages to the environment.

Now a day, high efficiency, maximum reliability and security in design and operation of power systems are more important. The difficulties in constructing new transmission lines due to limits in the rights for their paths, make it necessary to utilize the maximum capacity of transmission lines. Therefore, it would be difficult to provide the voltage stability even in normal condition. FACTS devices can be considered as viable and feasible options for satisfying the voltage security constraints in modern power systems due to their response in the urgent circumstances is fast, performance is flexible and they also applicable in dynamic situations. The effectiveness of the FACTS controllers mainly depends on their location.

Many researches have been carried out in the past to introduce the FACTS devices in the power system network. Wind based plants are also considered in the past for study. References [1,2] have been shown that in European as well as a global perspective among the non-conventional energy sources, wind power is undergoing rapid development. The authors focus on the cost structures of a wind power plant with incorporating the lifetime of the turbine, operation and maintenance costs. It also analyses how the costs of wind power have developed in previous years and how they are expected to develop in the near future. Chang et al. [3] analyze the impacts on the economic operation of a power system, bus voltage and transmission losses on the system after installation of large numbers of WTG instead of a single WTG in the system. In [4], it is investigated that how independent wind power producers optimally offer their variable power into a competitive electricity market for energy. As wind is an inherently variable source of energy, the authors explore the sensitivity of optimal expected profit to uncertainty in the underlying wind process. Vazquez and Kirschen [5] present a methodology for quantifying

* Corresponding author.
E-mail addresses: subhojit.dawn@gmail.com (S. Dawn), prashant081.in@gmail.com (P.K. Tiwari).

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Nomenclature

TCSC	thyristor controlled series compensator
GENCOS	generation companies
MMP	multi-objective mathematical programming
WTG	wind turbine generator
GA	genetic algorithm
IA	immune algorithm
POPF	probabilistic optimal power flow
SVC	static VAR compensator
CI	computational intelligence
PST	phase-shifting transformer
SW	social welfare
Y_{ik}, θ_{ik}	magnitude and angle of element of ith row and kth column of bus admittance matrix
$Cost_{TCSC}$, $Cost_{UPFC}$	investment cost of TCSC & UPFC
$\|Q_A\|$, $\|Q_B\|$	reactive power flow in the line after and before placement of FACTS devices
$AICost_{FACTS}$	annual investment cost of FACTS devices
P_{Gi}	power generation at ith generation unit
$C_i(P_{Gi})$	generation cost curve at generator bus 'i'
HIC_{FACTS}	hourly cost of FACTS devices
P_{loss}, P_L	transmission loss and power demand
G_J	conductance of line, connected between buses 'i' and 'j'
Q_{UPFC}^{min}, Q_{UPFC}^{max}	limit of reactive power injected or absorbed by shunt converter of UPFC
P_i, Q_i	real and reactive power injected into the system at bus number 'i'
V_i^{min}, V_i^{max}	lower and upper voltage limit of bus 'i'
TL_l, TL_l^{max}	actual and maximum line flow limit of line 'l'
k_{TCSC}^{min}, k_{TCSC}^{max}	lower and upper compensation level of TCSC
ND	total number of loads present in a system
WGC	Wind Generation Cost
IPSO	immune particle swarm algorithm
DISCOS	distribution companies
FACTS	flexible alternating current transmission systems
IGA	immune genetic algorithm
DE	differential evolution
HIA	hybrid immune algorithm
UPFC	unified power flow controller
OPF	optimal power flow
ISO	independent system operator
HFC	hybrid flow controller
LMP	locational marginal pricing
x_{TCSC}, k_{TCSC}, x_{UPFC}, K_{UPFC}	reactance and compensation co-efficient of TCSC & UPFC respectively
OP_{FACTS}	operating point of FACTS devices
N_b, NG, N_l	total number of buses, generators and transmission lines of a system
ir, LT	interest rate and lifetime of FACTS devices
$B_j(PD_j)$	benefits of consumers at load bus 'j'
C_{FACTS}, C_{WPG}	investment cost of FACTS devices and wind power generator
WPG	Wind Power Generator
P_{WPG}	generated power from wind power generator
$\|V_i\|$, $\|V_j\|$, V_k	voltage magnitude of bus 'i', bus 'j' and bus 'k'
x_{line}, x_{LINE}	line reactance between bus i & j after TCSC, UPFC placement
$INCost_{FACTS}$	overall investment cost of FACTS device
ϕ_i^{min}, ϕ_i^{max}	lower and upper phase angle limit of voltage at bus 'i'
$P_{Gi}^{min}, P_{Gi}^{max}, Q_{Gi}^{min}, Q_{Gi}^{max}$	lower and upper limit of real & reactive power of bus 'i'
$K_{UPFC}^{min}, K_{UPFC}^{max}$	lower and upper compensation level of UPFC
N_{TCSC}, N_{UPFC}	number of TCSC & UPFC connected to system
δ_i, δ_j	voltage angle of bus 'i' and bus 'j'

fully the effect of wind power generation on the various components of the operating costs in the system. Paper [6] deals with optimal placement of the energy storage units within a deregulated power system to minimize its hourly social cost. Based on an electricity market model, the authors minimize the hourly social cost using POPF then use GA to maximize wind power utilization over a scheduling period. Shaheen et al. [7] present an approach that is based on the DE to optimize the placement & parameter setting of UPFC for amplifying power system security under single line contingencies. Authors have been done the work with small networks only like IEEE 14-bus and an IEEE 30-bus systems. References [8,9] represent the application of IA, HIA, IGA & IPSO to find out the optimal location of UPFC. The objective function including total active & reactive production cost function of generators and installation cost of UPFC are considered and it has been minimized. Mondal et al. [10] present an approach to select the optimal location and parameters setting of SVC and TCSC using PSO to mitigate small signal oscillations in a multi-machine power system.

Reference [11] proposes an approach for secured optimal power flow under normal condition and network contingencies with the help of optimal placement of TCSC. In this approach, two consecutive steps have been used by the authors. First, the optimal location of the TCSC in the network must be ascertained by min cut algorithm and then, the OPF with TCSC under normal and contingencies operating condition is solved. In [12,13], authors have proposed DE, GA and CI techniques to optimal placement and parameter setting of TCSC for minimizing the active power losses and enhancing power system security under single line contingency in the power network. The authors have used 3-bus, 5-bus, IEEE 6–bus and IEEE-14 bus power system to validate their results. References [14,15] propose an investment cost recovery based optimization approach to the optimal allocation of TCSC in deregulated power market with the objective to maximize the social welfare and minimize the device investment cost by suitable location and rating of single TCSC in a power system. The authors have used 5-bus system, modified IEEE 14-bus system and 246-bus NRPG systems to validate their results. Reference [16] discusses various aspects of UPFC control modes, settings and evaluates their impacts on the power system reliability. A power injection model is used to represent UPFC and a comprehensive method is proposed to select the optimal UPFC control mode and settings. Paper [17] develops a model of FACTS shunt-series controllers for multi objective optimization and also presents an optimization methodology to find the optimal location of shunt-series FACTS controllers. The approach is implemented for the formulation of MMP which includes the FACTS shunt-series controllers (PST), HFC and UPFC. Simulation results are presented for the IEEE 14-bus system. Reference [18] presents an approach to optimal allocation of UPFC in a pool and bilateral market. The main objectives of the paper are to formulate an optimization technique to maximizing SW by suitable placement, suitable number and rating of the UPFC in a power system working under a deregulated environment. The effectiveness of the proposed technique has been tested on the 39-bus New England system with addition of four bilateral transactions.

After the careful and comprehensive literature review it has been found that the following points still need to be answered: (a) What are the effects of wind generation system on power