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Zonal do-not-exceed limits with robust corrective topology control

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ABSTRACT

The penetration of renewable resources in electrical power systems has increased over the years. This increased levels of intermittent resources adds complexities in power system operations. At the Independent System Operator of New England (ISONE), in real-time operation, the renewable resources are integrated into the system using do-not-exceed (DNE) limits. The determination of DNE limits, in real-time, is challenging; to reduce the computational time, approximations are made and mathematical models are simplified. In this paper, a zonal approach is proposed to determine DNE limits, which reduces the network model into few interlinked zones. The approximations with the zonal approach do not affect the quality of solution to a great extent. However, they reduce the computational time so that the zonal DNE limits approach may be implemented in real-time. The DNE limits determined with the zonal approach are compared with the detail nodal DNE limits on a smaller IEEE-118 bus test case and a realistic system provided by Tennessee Valley Authority (TVA).

1. Introduction

As the penetration of stochastic resources (e.g., variable wind and solar power) increases in power systems, the challenge to maintain a continuous supply of electrical energy, at minimal cost, has increased. Traditionally, economic dispatch models, used in system operations, are deterministic and do not optimize system resources while explicitly accounting for uncertain resources. In order to reduce operational costs, while maintaining reliability, uncertainty modeling plays an important role in the decision making process; by ignoring uncertainty, the operational decision can be suboptimal or even infeasible.

Today, in most optimal dispatch models, conventional fossil-fuel generators are dispatched to a fixed operating point known as desired dispatch point (DDP). In these models, it is assumed that the conventional generators can operate at a fixed operating point for the desired time period. However, this assumption cannot be made for semi-dispatchable or non-dispatchable renewable resources because of their inherent intermittent nature and limited operational control. Therefore, in such cases, system operators instruct renewable power producers to operate within the desired dispatch range, so that these uncertain resources will be at a fixed operating point. At the Independent System Operator of New England (ISONE), this dispatch range is known as a do-not-exceed (DNE) limit for intermittent wind power producers [1]. The DNE limit defines a continuous set of potential dispatch solutions for the renewable resource; this continuous set of dispatch solutions that can be viewed as an uncertainty set. The bounds of the DNE limit are meant to be set such that if the renewable resource stays within the specified DNE limits (i.e., the upper and lower bound), then the system will remain in a secure and reliable operating state [1].

In ISONE's DNE limit formulation, only generators with active automatic generation control (AGC) are considered to respond to intermittencies in wind generation [1]. In real-time application, such approximation is justified because expected uncertainty in renewable generation is relatively smaller in real-time operating state. However, traditionally, AGC is used for load following and addressing small perturbations in system operation. If all available AGC is used to address renewable generation intermittency, additional resources may be required for load following and system perturbations. In [1], details about these additional resource requirements are not presented but these additional resources can be obtained with more frequent and more accurate dispatch instruction to conventional generators or by committing additional generators [2]. Furthermore, in [1], the DNE limits are determined close to real-time operation, where more accurate information about the quantity and location of AGC is available. However, in day-ahead or hour-ahead timeframe, the AGC based approach restrict the capabilities of DNE limits, as generator output or DDP changes over time due to change in system demand and renewable generation. At the same time, in day-ahead timeframe, accurate

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Indices

n, m	zones.
g	generator.
$g(n)$	set of generators at zone n.
w	set of wind injection locations.
$w(n)$	set of wind generators at zone n.
k	transmission asset (line or transformer).
$\delta(n)^+$	set of lines with n as the "to" zone.
$\delta(n)^-$	set of lines with n as the "from" zone.
cut	set of cuts added to the master problem.
n	number of buses.

Parameters

$P_g^{\max}$	max real power supplied by generator g.
$P_g^{\min}$	min real power supplied by generator g.
$P_w^{\max}$	max real power supplied by wind farm w.
$P_w^{\min}$	min real power supplied by wind farm w.
R_g^{+c}	max 10 min ramp up rate for generator g.
R_g^{-c}	max 10 min ramp down rate for generator g.
u_g	unit commitment status of generator g.
P_g^*	real power supplied by generator g at zone n (solution obtained from unit commitment).
d_n	real part of system demand at zone n.
B_k	electrical susceptance of transmission line k.
$P_k^{\max}$	max capacity of transmission line k.
P_w^*	forecasted real power supplied by wind generators connected at zone $w(n)$.
M_k	big-M value for transmission line k.
M_n	big-M value for zone n.
δ	penalty for constraint violation. Set to 1.
$PTDF_{k,i}^R$	power transfer distribution factor over line k for an injection at bus i sent to the reference bus R.

Variables

P_w^{UP}, P_w^{LP}	max and min wind injection deviation at zone n, from its forecasted level.
P_w, P_w^{ub}, P_w^{lb}	real power supplied by wind generator w.
P_g, P_g^{ub}, P_g^{lb}	real power supplied by generator g.
P_k, P_k^{ub}, P_k^{lb}	real power from node m to n for line k.
$\theta_n, \theta_n^{ub}, \theta_n^{lb}$	voltage angle at zone n.
Z_k	binary parameter for transmission element k; 0 if line is open/not in service; 1 if line is closed/in service.
L_n^+, L_n^-	violation in the node balance constraint at zone n.
γ_k^+, γ_k^-	violation in the line flow limits of line k.

determination of AGC, in terms of location and quantity, is difficult and may result in inaccurate DNE limits.

Past research has shown benefits of topology control (TC) for system operation and reliability. Today, most of the TC decisions are determined based on operators' past knowledge or other ad-hoc methods. The review of current TC related industrial practices are discussed in [3,4]; furthermore, at PJM, TC actions are included in the transmission manual as corrective solutions for reliable power system operations [5]. In literature, TC has been proposed to mitigate many power system related issues. In [6–10], TC is used to overcome voltage violations and line overloads; in [11–14], TC is used for line losses and operational cost reduction. TC is also proposed to improve system security and operational flexibility [3,15,16]. TC has shown significant improvement in operational flexibility [3] and cost saving [17–19,14]. TC has also shown benefits in transmission planning studies [20].

Robust optimization has shown promising results in recent years to address issues associated with modeling uncertainty and decision making under uncertainty. In [21,22], a two-stage robust optimization technique is used to solve the unit commitment problem. Robust optimization deals with the data uncertainty and tries to find an optimal solution considering the worst-case uncertainty realization. The solution of the robust optimization problem is guaranteed to be optimal for a defined uncertainty set [3,23,21,22,24–26]. Since the optimal solution is a hedge against the worst-case realization, the solution is often conservative and probably expensive. For the application of power system reliability, such a robust policy is preferred due to the enormous costs of a potential blackout.

In general, TC algorithms are either based on the AC optimal power flow (ACOPF) or the DC optimal power flow (DCOPF) [3,6,13]. However, in a robust optimization framework, there is no simple method to insure AC feasibility of TC actions. The zonal DNE limit formulation, presented in this paper, is based on DCOPF; therefore, the TC solution, obtained from the zonal DNE limit problem, is tested for the AC feasibility to ensure that the TC action will provide AC feasible operating point.

The main contributions of this paper are summarized below.

1. Identified the limitations of the DNE limits procedure used by ISONE. The AGC based DNE limit procedure may not be sufficient to determine the DNE limits at the day-ahead timeframe. In this paper, a more generic methodology to determine the DNE limits is presented, which is capable of determining the DNE limits in a day-ahead as well as in a real-time timeframe.
2. Addressed the scalability issue of the robust DNE limit problem. In this paper, a zonal DNE limit procedure is proposed, over the detailed nodal approach, to determine DNE limits.
3. Formulated the zonal DNE limit problem using robust optimization techniques. The proposed solution method to determine the DNE limits is a two stage process and capable of determining the DNE limits with and without TC. The proposed solution method is tested on two different test systems: the IEEE-118 bus test system and the Tennessee Valley Authority (TVA) system. The zonal DNE limit formulation is based on DCOPF; therefore, the TC solution obtained from the DNE limit algorithm needed to be tested AC feasibility.

The paper is structured as follows: the zonal DNE limits approach is described in Section 2. The clustering method, used in this paper, to determine system zones is presented in Section 3. The mathematical model for the zonal DNE limit approach is presented in Section 4. The solution method for the zonal DNE limit problem is presented in Section 5. The associated simulation results for the zonal DNE limit algorithm, on IEEE-118 bus test system is presented in Section 6. In Section 7, simulation results related to TVA test system are presented. Section 8 provides the conclusions and discusses potential future work.

2. Zonal DNE limits

In [1], a procedure to determine real-time DNE limits without TC is presented. At ISONE, the DNE limits are determined, for the real-time application, considering the real-time (5 min ahead) dispatch instructions to conventional generators. The real-time DNE limits demands fast solution time, which necessitates to simplify the DNE limit problem and restricts the problem modeling details. In [1], the DNE limit formulation, used at ISONE, is presented, which consists of energy balance constraints, line flow constraints, and generator capacity constraints. However, in actual implementation, to reduce the computational time, only a handful of transmission