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An improved method to calculate injection shift keys

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ABSTRACT

Transmission network constraints become increasingly relevant in generation scheduling models, given the ongoing integration of market zones and the deployment of renewables in remote areas. However, a full nodal network representation in generation models is often not possible due to computational limitations. Therefore, reduced zonal network models are needed. A crucial step in the nodal-zonal network reduction is the calculation of injection shift keys (ISKs). Injection shift keys denote the nodal contribution to the zonal generation balance and are needed to compile different nodes into one equivalent node. This paper discusses injection shift keys in detail and proposes an improved method to calculate them. According to the improved method, the generation and load portfolio is split up in different categories, and injection shift keys are determined separately for each category. A case study of the central European electricity system indicates that the improved method is able to approximate the nodal network without a considerable increase in computational cost.

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1. Introduction

A proper representation of transmission networks in electricity system models is becoming increasingly important. Given the integration of different market zones and the deployment of renewables in sometimes remote areas in the network, transmission constraints become more relevant and should hence be taken into account in operational and planning models of the electricity generation sector [1]. A full implementation of the network in this kind of models is not always feasible due to the large size of real-life networks and the concomitant high computational cost. Therefore, reduced network models are needed, representing as good as possible the characteristics of the full network model without jeopardizing the computational tractability.

Reduced network models can also be relevant for congestion management purposes in electricity markets [2]. Policy makers might prefer a reduced network model to a full network implementation for, besides computational reasons, historical and socio-political reasons. For instance, current electricity markets in Europe are based on a strongly reduced model of the electricity network.

A standard network reduction technique is equivalencing of the external network by computing impedances and eliminating unnecessary elements [3–8]. Equivalent networks have been used for short circuit analysis as they can reproduce the voltages and currents of the remaining buses. However, equivalent networks are not able to approximate flows of the eliminated branches. Therefore, the usage of equivalent networks is limited in power flow analysis [9]. Another network reduction technique consists of grouping nodes in a limited number of zones, hereby reducing the number of nodes in the network [10,11]. A zone is assumed to be a copper plate, meaning that transmission constraints within a zone can be neglected. The remaining transmission lines between zones can be grouped in inter-zonal links. This second network reduction technique is referred to as the nodal-zonal reduction in this paper.

The nodal-zonal reduction technique starts from a full nodal description and derives a simplified zonal network in three sequential steps. First, nodes with similar electric characteristics are clustered in zones [12–16]. Second, nodes within a zone are replaced by an equivalent node with – approximately – the same relationship between power injections in the network and power flows through the remaining inter-zonal lines [17,18,9,19]. Third, the remaining inter-zonal lines between two zones can be replaced by one equivalent inter-zonal link [12,20].

A full non-linear AC power flow would be the most accurate network representation in electricity generation models [21]. However, due to the high computational cost of an AC power flow, a DC power flow is often preferred [22]. The DC power flow gives a linear relation between power injections and power flows by means of power transfer distribution factors (PTDF). The difference in power flows resulting from a DC and an AC model are estimated at about 5% on average for high voltage grids, although power flow

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Nomenclature

Sets

I (index i)	set of generation units
L (index l)	set of lines in nodal network
K (index k)	set of lines in zonal network
N (index n)	set of nodes
T (index t)	set of time steps
Y (index y)	set of all categories
Y_G (index y_G)	subset of generation-related categories
Y_L (index y_L)	subset of load-related categories
Z (index z)	set of zones

Parameters

$\mathbf{A}^{N,gen}$	N-by-I matrix linking generation units to nodes
$\mathbf{A}^{Z,gen}$	Z-by-I matrix linking generation units to zones
$\mathbf{B}^{bus}$	N-by-N bus admittance matrix
$\mathbf{B}^{bus*}$	(N − 1)-by-(N − 1) reduced bus admittance matrix
$\mathbf{B}^{branch}$	L-by-N branch admittance matrix
$\mathbf{B}^{branch*}$	L-by-(N − 1) reduced branch admittance matrix
$\mathbf{D}^{N}$	N-by-1 vector with nodal load
$\mathbf{D}^{Z}$	Z-by-1 vector with zonal load
$\bar{\mathrm{F}}^{N}$	L-by-1 vector with line capacities in nodal network
$\bar{\mathrm{F}}^{Z}$	K-by-1 vector with line capacities in zonal network
$\mathbf{F}^{Z,0}$	K-by-1 vector with base case flows in zonal network
$\bar{\mathrm{G}}$	I-by-1 vector with maximum power output of the generation units
ISF	L-by-N matrix with injection shift factors
ISF*	L-by-(N − 1) matrix with reduced injection shift factors
ISK	N-by-Z matrix with injection shift keys
$\mathbf{ISK}^{Y}$	N-by-Z matrix with injection shift keys of category Y
MC	I-by-1 vector with the marginal generation costs
$\mathbf{PTDF}^{N}$	L-by-N matrix with nodal power transfer distribution factors
$\mathbf{PTDF}^{N*}$	K-by-N matrix with node-to-link power transfer distribution factors
$\mathbf{PTDF}^{Z}$	K-by-Z matrix with zonal power transfer distribution factors
$\mathbf{PTDF}^{Z,Y}$	K-by-Z matrix zonal power transfer distribution factors of category Y

Variables

$\boldsymbol{\theta}$	N-by-1 vector with nodal voltage angles
$\mathbf{F}^{N}$	L-by-1 vector with line flows in nodal network
$\mathbf{F}^{Z}$	K-by-1 vector with line flows in zonal network
G	I-by-1 vector with power output of the generation units
$\mathbf{P}^{N}$	N-by-1 vector with nodal power injections
$\mathbf{P}^{N,Y}$	N-by-1 vector with nodal power injections of category Y
$\mathbf{P}^{Z}$	Z-by-1 vector with zonal power injections
$\mathbf{P}^{Z,Y}$	Z-by-1 vector with zonal power injections of category Y

deviations for single lines can be larger [23]. In this paper, a DC power flow representation of the network is discussed.

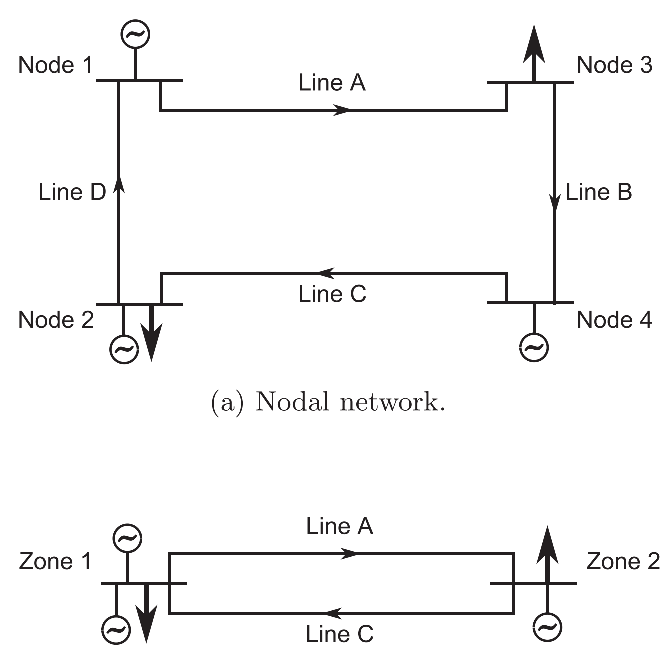
This paper deals with the second step in the nodal-zonal reduction, i.e., grouping nodes in an equivalent node. A commonly used grouping approach is based on injection shift keys (ISKs) [24]. ISKs are a mathematical expression of the spatial distribution of electricity generation and load within a zone. Each node within the zone contributes to the equivalent node in accordance with its ISK. ISKs are an important parameter, influencing the nodal-zonal reduction to a great extent. Nevertheless, different formulas can be found in the literature to calculate ISKs. Certain papers consider both generation and load, and determine the ISK as the nodal contribution relative to the zonal balance (see for instance [9]). Other papers consider only generation, and determine the ISK as the nodal generation relative to the total generation in the zone (see for instance the flow-based market coupling methodology [25]). It is often unclear why a certain ISK calculation method is preferred. Moreover, ISKs are time-dependent as the spatial distribution of generation and load changes in time. This results in time-averaging errors when a daily or weekly average zonal network model is needed.

The added value of this paper to the existing literature is twofold. First, the paper presents a thorough discussion of ISKs, with a detailed overview of the different steps needed to calculate them and use them in zonal grid models. Based on this paper, the reader can evaluate different ISK calculation methods presented in the literature. Second, an improved method to calculate ISKs is proposed. The method is based on the insight that ISKs are calculated more accurately when the generation and load portfolio is split up in different categories. This improved method allows, for instance, taking flexible load into account as a variable in the zonal grid model.

The paper proceeds as follows. Section 2 presents in detail the nodal-zonal network reduction technique. Section 3 discusses the challenges related to injection shift keys and proposes an improved method to calculate them. This improved method is evaluated in Section 4 based on a case study of the central European electricity network. Section 5 concludes.

2. Nodal-zonal network reduction

The nodal-zonal network reduction starts from a full nodal PTDF-matrix and ends up with a simplified zonal PTDF-matrix. The nodal-zonal reduction method is illustrated by a simple example (see Fig. 1).



(a) Nodal network.

(b) Zonal network.

Fig. 1. Simple electricity network to illustrate the nodal-zonal network reduction. Generation units are located at node 1 (base load unit), node 2 (peak load unit) and node 4 (base load unit). Load is located at nodes 2 and 3. Zone 1 consists of nodes 1 and 2, zone 2 of nodes 3 and 4.

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