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Grid model reduction for large scale renewable energy integration analyses

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Abstract

This paper provides a brief description of an algorithm for generating equivalent, reduced power flow models. It presents the underlying principles and the various steps of the reduction process. The procedure is applied to two different cases: The Moroccan power system and the Norwegian power system. The derived reduced, equivalent models are briefly discussed and compared with the full models. The model reduction procedure and its implementation as Matlab/Python scripts is generic and may be applied for reduction of any grid model described by a PSSE load flow file.

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1. Introduction

It is often useful to perform analyses with simplified models in order to gain a clearer understanding of specific phenomena, avoiding "noise" from less relevant issues. Additionally, simplifications means reduced effort in terms of time or computational power. When working with simplified models it is of course important that the simplification keeps the most important characteristics of the real case. In other words, good reduction procedures are essential.

This document outlines a reduction procedure for an electricity grid model that is suitable for optimal power flow analyses of large interconnected power systems. The idea of this reduction procedure is to reduce the number of nodes and branches starting from a detailed grid model and arriving at an *equivalent* model with an arbitrarily chosen number of nodes. Equivalence in this case means that the reduced model exhibits similar power flow characteristics.

The reduction procedure is based on and previously described in refs. [1] and [2]. It includes a well-defined algorithm for bus aggregation based on power transfer distribution factors (PTDFs), and computation of branch reactances in the reduced model based on similarity of PTDFs and voltage angles, with appropriately chosen weighting.

The application of such reduced grid models may be several, but the main one foreseen at present is the analysis of the impacts of large scale integration of renewable energy in the European and North African power systems. Similar

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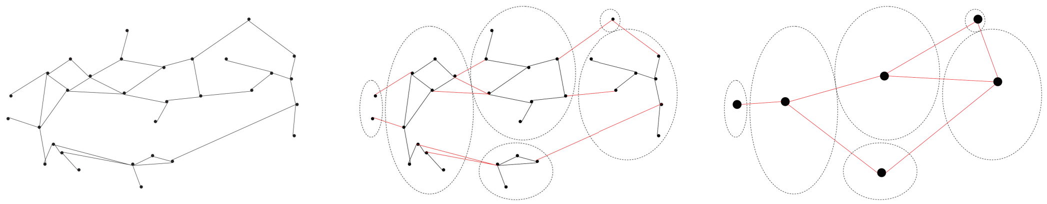

(a) Original grid (b) Clustering (c) Reduced grid

Fig. 1: Principle of grid reduction. a) The original full model, for which the full PTDFs are computed. b) Zones are uniquely defined explicitly, or by a clustering algorithm. Zone-crossing lines are shown in red. c) In the reduced model, each zone is represented by one node, and connections between zones by single lines.

analyses have been done in the past with emphasis on future scenarios for wind energy in Northern Europe [3,4]. Such analyses may give valuable insight into power system bottlenecks and price variations. The results are useful in understanding power system impact of large scale integration of renewable energy, and for timely planning of grid reinforcements.

The reduction procedure described and applied here is one of several proposed approaches, see e.g. [5,6,7,8,9,10]. It has been chosen since it is particularly suitable for power flow analyses of large power systems.

2. Grid reduction algorithm

This section describes a generic algorithm for creating a reduced model that pertains power flow characteristics of the original model. The purpose of this reduction is to reduce computational demands, and to arrive at a model more suitable for high level analyses involving multiple countries. An added benefit may be that the reduced model can more easily be be shared publicly or at least amongst research partners, as the model reduction involves an aggregation and obscuration of sensitive grid data. The procedure is based on work published by others [1,2], and so the following description is kept concise. For more thorough treatment of the concepts presented, the reader is referred to the cited literature.

This reduction process is a *static* reduction based on a snapshot of the power system at one particular point in time. This of course means that the reduced model is less accurate for operating conditions differing significantly from what they are at this time. Figure 1 shows the principle of reducing the full grid to a smaller, equivalent model.

2.1. Power transfer distribution factors (PTDF)

Power transfer distribution factors (PTDFs) are a way to express power flow characteristics of a grid model. They are represented as an $N \times L$ matrix, where N equals the number of nodes (buses) and L equals the number of branches (connections between nodes). The elements of the PTDF matrix specifiy how power flows from a given injection point to a chosen extraction point (sink). That is, the value of the element in row $n \in N$ and column $l \in L$ specifies how large a fraction of the power goes through branch l when one power unit is injected at node n and extracted at the sink node. The sink node is given, and is typically taken to be the slack bus used for power flow analyses.

The PTDF matrix is used in the grid model reduction algorithm both for clustering of nodes, and as a key element for computing equivalent reactances in the reduced model. The idea is that the PTDF matrix from the reduced model should be as similar as possible to the PTDF matrix of the original, full model. Basing the model reduction on the PTDF equivalence is appropriate when creating models that will be used for power flow analyses.

2.2. Node clustering

If the input model is already separated into areas that represent geographical zones, it may be possible to use one cluster per zone. Or if zone borders are given beforehand, the clustering can be achieved by identifying all zone-crossing connections. However, if information about the grid model is limited, performing such explicit clustering may be difficult, or at least time consuming.