Model fidelity and its impact on power grid resource planning under high renewable penetration

by

Daniel Xavier Wolbert

A Thesis
Presented to the Graduate Committee
of Lehigh University
in Candidacy for the Degree of
Master of Science
in
Industrial and Systems Engineering

Lehigh University
05/2106

Approved and recommended for acceptance as a thesis in partial fulfilment of the requirements for the degree of Master of Science.

Daniel Xavier Wolbert
Model fidelity and its impact on power grid resource planning under high renewable penetration

05/06/2016

Tamas Terlaky, Thesis Director, Chair
(Must Sign with Blue Ink)

Accepted Date

Committee Members

Robert H. Storer

Contents

List of Tables v

List of Figures vii

Abstract 1

1 Introduction 3

2 Literature Review 5

3 Development 7

3.1 Data 7

3.2 Models 7

3.2.1 Indices and Sets 7

3.2.2 Parameters 8

3.2.3 Variables 8

3.2.4 Economic Dispatch Models 8

3.3 Implementation 10

4 Analysis 11

5 Conclusion 13

Vita 15

List of Tables

List of Figures

This is the abstract no

Chapter 1

Introduction

Chapter 2

Literature Review

Chapter 3

Development

3.1 Data

3.2 Models

This thesis covers the Economic Dispatch and Unit Commitment models, developed exhaustively in the literature.

3.2.1 Indices and Sets

$g \in \mathcal{G}$	Set of generators
$b \in \mathcal{B}$	Set of buses
$g \in \mathcal{G}^{NR}$	Subset of non-renewable generators
$g \in \mathcal{G}^{R}$	Subset of renewable generators
$gt \in \mathcal{GT}$	Set of generator types
$u \in \mathcal{U}$	Set of unit groups
$l \in \mathcal{L}$	Set of transmission lines
$rr \in \mathcal{RR}$	Set of reserve requirements
$rp \in \mathcal{RP}$	Set of reserve products
$t \in \mathcal{T}$	Set of time periods
$g \in \mathcal{G}^{\lfloor}$	Set of generators in each bus b

3.2.2 Parameters

$D_{b,t}$	Load at bus b in time t
C_g	Generation cost for generator g (\$ / MW) t
S_g	Start-up cost for generator g
R_g^{up}	Ramp up limit for generator g
R_g^{down}	Ramp down limit for generator g
G_g^{max}	Maximum generation capacity for generator g
G_g^{min}	Minimum generation capacity for generator g
T_l^{min}	Minimum transmission of transmission line l
T_l^{max}	Maximum transmission of transmission line l
$P_{g,t}^R$	Power generation of renewable generator g in time t

Note 1: The generation of renewable resources are not in the decision variables. The developed models only decides the generation for non-renewable resources. Therefore the generation is considered a deterministic parameter, not a variable in the model.

3.2.3 Variables

$P_{g,t}^{NR}$	Power generation of non-renewable generator g in time t (MW)
$T_{i,j,t}$	Power transmitted from bus i to bus j in time t (MW)
$T_{i,j,t}^{loss}$	Power loss in transmission from bus i to bus j in time t (MW)
$S_{g,t}$	On/off status of generator g at time n
$S_{g,t}^{on}$	Start-up status of generator g at time n
$S_{g,t}^{off}$	Shut-down status of generator g at time n
$V_{b,t}^-$	Under generation slack variable at each bus b in time t
$V_{b,t}^+$	Over generation slack variable at each bus b in time t

3.2.4 Economic Dispatch Models

The economic dispatch model satisfies the load and transmission requirements at a minimum cost, following operational requirements such as generation, transmission and ramp limits. In this model, we assume that the commitment decisions has been already made.

Simple Economic Dispatch Model

$$\begin{aligned}
min \quad & \sum_{t \in T} \sum_{g \in G^{NR}} P^{NR}_{g,t} C_g + \sum_{t \in T} \sum_{b \in B} V^{-}_{b,t} + \sum_{t \in T} \sum_{b \in B} V^{+}_{b,t} && && (3.1a)\\
s.t. \quad & \sum_{t \in T} P^{NR}_{g,t} + \sum_{t \in T} P^{R}_{g,t} + \sum_{t \in T} V^{-}_{b,t} = \sum_{t \in T} D_{b,t} + \sum_{t \in T} V^{+}_{b,t} \ \forall t \in T && && (3.1b)\\
& P^{NR}_{g,t} - P^{NR}_{g,t-1} \leq R^{up}_{g} && \forall t \in T, g \in \mathcal{G}^R && (3.1c)\\
& P^{NR}_{g,t-1} - P^{NR}_{g,t} \leq R^{down}_{g} && \forall t \in T, g \in \mathcal{G}^R && (3.1d)\\
& G^{min}_{g} \leq P^{NR}_{g,t} \leq G^{max}_{g} && \forall t \in T, g \in \mathcal{G}^R && (3.1e)
\end{aligned}$$

The constraint 3.1b states the energy balance in every time. The constraints 3.1d and 3.1c states that every generator has to obey the ramp limits. The constraint 3.1e states the generation limits for each generator. The use of slack variables $V^{-}_{b,t}$ and $V^{+}_{b,t}$ is necessary to always have feasible solutions, and it is important for scenarios where there is a huge renewable penetrations, when there's an abrupt variation of generation and there is a over or under generation.

Economic Dispatch with Transmission Constraints

In this case, the model has to consider transmission limits and losses, without transmission costs associated. The objective function 3.1a remains the same, and the constraints 3.1c, 3.1d and 3.1e are als used. The constraint 3.1b is replaced by

$$\sum_{g \in G^b} P^{NR}_{g,t} + \sum_{g \in G^b} P^{R}_{g,t} + \sum_{b^{in} \in B} T_{b^{in},b,t} + V^{-}_{b,t} = D_{b,t} + V^{+}_{b,t} + \sum_{b^{out} \in B} T_{b,b^{out},t} \ \forall b \in B, t \in t \tag{3.2a}$$

$$T^{min}_{l} \leq T_{b^{in},b^{out},t} \leq T^{max}_{l} \qquad \forall b \in B, t \in t \tag{3.2b}$$

Constraint 3.2a guarantees that the energy balance is always satisfied for every bus: everything that is generated and received from other buses should be equal to what is loaded and sent throughout the line with the respective losses. If this balance is not satisfied then it is represented in the slack variables. (TODO: put lossed in the equation). The constraint 3.2b defines the transmission bounds for each line.

Economic dispatch model with unit commitment constraints

This optimization model is a mixed-integer linear program (MILP). This model includes decision variables to capture "on" and "off" decisions for thermal generators in each time period. The objective function must be modifies to account for start up and shut down costs with thermal generators.

3.3 Implementation

Here write about how it was implemented, in AIMMS, put some running times in a table, some images, put a brief description about what is AIMMS and why it is used, and etc. If i Cite this one, will it apeaar? **?**

Chapter 4

Analysis

In the analysis make all the scenario runs, describe the data.

Chapter 5

Conclusion

Bibliography