Electrical Power and Energy Systems 102 (2018) 245–253

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Consideration of Network Constraints in the Turkish Day Ahead Electricity Market

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A R T I C L E I N F O

Keywords:
Turkish day-ahead electricity market
Network model
Security Constrained Unit Commitment

A B S T R A C T

This paper proposes a new model for the Turkish Day Ahead Electricity Market including network equations. The existing one does not implicitly consider the power flow limitations, and these are considered separately that might result with a suboptimal day-ahead schedule. The dc network equations are added to the model, which is used to determine the Day Ahead System Sell and Buy Decisions and System Marginal Price in day-ahead planning. The impact of integration of network equations is exhibited using a small 6-bus network, mid-sized Turkish northwest sub-system, and full Turkish electric power system.

1. Introduction

Turkey employs a growing electric energy sector with its installed electric generation capacity of 83.14 GW by the end of November 2017 and annual generation was realized as 273.4 GWh in year 2016. The share of government generation company (EUAS) capacity is 24% by the end of 2017, while the rest belongs to private entities. The shares of hydroelectric, thermal and renewable capacities are 32.7%, 55.3% and 12% respectively [1]. Turkish Electricity Authority (TEK), established in 1970, was a statutory monopoly until 1984. The participation of private sector starts in 1984 under different modes including Build-Operate-Transfer (BOT), Build-Own-Operate (BOO) and Transfer of Operating Rights (TOOR). In 1993, TEK was split into two state-owned companies including Turkish Electricity Generation-Transmission (TEAS) and Turkish Electricity Distribution Company (TEDAS). Finally, TEAS was unbundled into three different companies responsible for different sub-sectors including EUAS (generation), TEIAS (transmission) and TETAS (wholesale) with Electricity Market Law issued in 2001. The unbundling of ownership followed as the government proceeded with its privatization plan of state-owned electricity generation and distribution sector companies, except for transmission company TEIAS. The new law also set the stage for a new organization, the Energy Market Regulation Agency (EMRA), which would oversee the power and natural gas markets including setting tariffs, issuing licenses, and assuring competition [2]. The 21 distribution regions are fully operated by private Distribution Companies by the end of year 2013 [3]. The Day Ahead Market mechanism was put in force in 2011, advance and collateral payment mechanisms and renewable energy support programs have started. Electricity Markets were run under TEİAŞ-Markets Financial Arbitration Center (PMUM) until 2015. Energy Exchange Istanbul (EXIST) company was started in 2015 and Day Ahead Market and Intraday Markets were started to be operated under EXIST while Ancillary Services and Balancing Market is still operated by TEİAŞ [4].

A number of studies exist in the literature considering Turkish Electricity Market. Ref. [5] proposes an extensive System Dynamics model which could be used by the regulators to analyze long-term effects of different policies. Various incentive policies namely; different renewable energy support policies, VOLL, CO2 taxes, enforced divestment, presence of long-term contract in the market and capacity addition limits on power plant types for the long-term analysis of the deregulated Turkish Market are discussed. Ref. [6] studies the Turkish Wholesale Electricity Market in general and takes a closer look to the Turkish balance and settlement system in particular. Ref. [7] compares mean-variance, down-side, and semi-variance methods for optimization in electricity markets to maximize the return while minimizing risk, and Turkish Electric Energy Market case study results are presented. Ref. [8] applies Markowitz mean-variance optimization technique for Turkish day-ahead electricity market. The energy allocation of hydraulic, lignite fired thermal and natural gas combined cycle power plants of National Generation Company (EUAS) between spot market and bilateral contract are performed utilizing the mentioned method. Ref. [9] investigates the importance of different aspects in order to achieve a successful design of a competitive electricity market. The authors address the impact of transmission network, demand locations, siting of generators from the system operator perspective while the importance of two strategies is noted from the investor/generator perspective. Ref. [10] focuses on the transformation of existing Turkish

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https://doi.org/10.1016/j.ijepes.2018.04.027
Received 13 January 2018; Received in revised form 17 March 2018; Accepted 23 April 2018

Nomenclature

Indices:

c	index of transmission lines
i	index of balancing unit
j	index of generating units
m	index of sell offers or buy bids
l	index of demands
t	index of time periods (hour)

Sets:

SHO	set of hourly sell offers
SBO	set of block sell offers
SD	set of demands
SFO	set of flexible sell offers
SHB	set of hourly buy bids
SBB	set of block buy bids
SFB	set of flexible buy bids
SG	set of generators
SGC	set of generalized generation constraints
STX	set of transmission lines
Ω_k	set of balancing units that appear in the constraint k

Variables:

HOQ	array of accepted amounts for hourly sell offers, the notation also applies to block and flexible sell offers and buy bids
HOQ_m	accepted amount for hourly sell offer m (MWh)
BOQ_m	accepted amount for block sell offer m (MWh)
$FOQ_{m,t}$	accepted amount for flexible sell offer m at time t (MWh)
HBQ_m	accepted amount for hourly buy bid m
BBQ_m	accepted amount for block buy bid m (MWh)
$FBQ_{m,t}$	accepted amount for flexible buy bid m at time t (MWh)
$f_{c,t}$	active Power transfer on transmission line c at time t (MW)
$g_{i,t}$	generation of balancing unit i at time t (MWh)
G_t	generation vector at time t (MWh)
x_m^{offer}	acceptance decision for not partially Acceptable sell offer m (binary variable. 0: reject, 1: accept)
x_m^{bid}	acceptance decision for not partially acceptable buy bid m (binary variable. 0: reject, 1: accept)
$y_m^{block\,offer}$	acceptance decision for block sell offer m (binary variable. 0: reject, 1: accept)
$y_m^{block\,bid}$	acceptance decision for block buy bid m (binary variable. 0: reject, 1: accept)
$z_{m,t}^{offer}$	acceptance decision for flexible sell offer m at time t. (binary variable. 0: reject, 1: accept)
$z_{m,t}^{bid}$	acceptance decision for flexible buy bid m at time t. (binary variable. 0: reject, 1: accept)
$\Delta_{c,t}$	adjusted angle for the phase shifting transformer located on transmission line c at time t.
Δ_t	adjusted angle array for the phase shifting transformers at time t.
	voltage angle of bus $b1$ connected to transmission line c at time t.
$\theta_{b2,t}$	voltage angle of bus $b2$ connected to transmission line c at time t.

Constants:

a_{ik}	coefficient of balancing unit i that appears in generalized constraint k
$\boldsymbol{A}$	generator bus incidence matrix
$\boldsymbol{B'}, \boldsymbol{B_\Delta}$	bus angle and phase shifting transformer incidence matrices
$\boldsymbol{C}$	load bus incidence matrix
b_k	right hand side limit for generalized constraint k
D_t	demand vector at hour t (MWh)
$f_{c,t}$	active power flow on line c
HOP_m	cost of hourly sell offer m (Turkish TL/MWh)
BOP_m	cost of block sell offer m (TL/MWh)
FOP_m	cost of flexible sell offer m (TL/MWh)
HBP_m	cost of hourly buy bid m (TL/MWh)
BBP_m	cost of block buy bid m (TL/MWh)
FBP_m	cost of flexible buy bid m (TL/MWh)
$\overline{HOQ}_m$	maximum amount for hourly sell offer m (MWh)
$\overline{BOQ}_m$	maximum amount for block sell offer m (MWh)
$\overline{FOQ}_m$	maximum amount for flexible sell offer m (MWh)
$\overline{HBQ}_m$	maximum amount for hourly buy bid m (MWh)
$\overline{BBQ}_m$	maximum amount for block buy bid m (MWh)
$\overline{FBQ}_m$	maximum amount for flexible buy bid m (MWh)
$\boldsymbol{K_t}$	sell offers generator incidence matrix for time t
$\boldsymbol{S_t}$	buy bids load incidence matrix for time t
$t0(m)$	hour of hourly buy bid/sell offer m
$Type(m)$	type of hourly buy bid/sell offer m (0: partially acceptable, 1: not partially acceptable)
$H(m)$	duration for block buy bid/sell offer m
$NETD_t$	net demand to be balanced at time t
$t1(m)$	starting hour for block buy bid/sell offer m
$t2(m)$	ending hour for block buy bid/sell offer m
$t3(m)$	hour for general generalized generation constraint k
$TypeGC_k$	type of generalized generation constraint k (-1: "$\leq$"; 0:"$=$"; 1:"$\geq$";)
x_c	reactance of line c

Abbreviations:

ISO	independent System Operator
MIP	mixed Integer Program
TL	Turkish Lira

Electric Power System into a smart grid. The authors point that Turkish Government has to take the necessary legislations and get the adequate encourage regulations for private generation and distribution level investments. Ref. [11] formulates the Turkish Day-Ahead Energy Market problem. A mixed integer formulation is presented and methods based on aggregation techniques and variable elimination to solve the problem within the limits of the practical requirements is provided. Ref. [12] analyze the matching algorithms for Day Ahead Markets in European Electricity Markets and show that those algorithms either heuristically solve the problem or even if optimization is intended, no public information are available about their time or gap performance.

While the upper mentioned studies analyze the electrical energy market in Turkey, other ones exist in the literature to consider the impact of network limitations in a Security Constrained Unit Commitment framework. The objective of security-constrained unit commitment (SCUC) is to obtain a unit commitment schedule at minimum production cost without compromising the system reliability. Ref. [13] models the simultaneous market clearing as an Optimal Power Flow (OPF) problem, considering AC network constraints and pre-defined ancillary services requirements. The OPF problem is solved by relaxing the system constraints through Lagrange multipliers, from which the definitions for price of energy and ancillary services are defined. Ref. [14] proposes a joint dispatch method to clear a multi-zonal electricity market. Hybrid sequential and joint market clearing is