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Real time procurement of energy and operating reserve from Renewable Energy Sources in deregulated environment considering imbalance penalties

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ABSTRACT

Renewable Energy Sources (RES) have prompted an additional burden on power system planners due to their stochastic nature. Hence it increases the need for Ancillary Services (AS) in power system. In deregulated electricity markets, AS has become an important issue because they are necessary for reliable and secure operation of a power system. Operating Reserve (OR), considered in this paper, is a measure of generators ability to increase their output under contingencies. ISO uses this service either for balancing purpose or for replacing the energy that had been scheduled to be provided by the unit that malfunctions. Thus establishing an efficient market for reserve services has become crucial. The premises of this paper is the development of penalty based Short-Term Market (STM) for the procurement of energy and OR. The effects of stochastic behavior of WPP on Social Benefit (SB) and Procurement Cost (PC) are investigated for the development of efficient STM. The proposed approach has been analyzed on IEEE-30 bus test system by implementing a sequential dispatch approach on various market structures. The results obtained under different market scenarios shows that there is a mandated requirement of effective penalty mechanism in order to discourage the imbalance behavior of RPPs.

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1. Introduction

Traditional power systems have been dominated by large Vertical Integrated Utilities (VIU) that performs all the activities related to generation, transmission and distribution of electric power within their obliged domain. These bundled utilities generally work under the regulated environment of the government jurisdiction [1]. During the early nineties, various electrical utilities of mostly developed economies have undergone through the unbundling process by changing their way of operation from being VIU to open market systems that consist of three independent components viz. Generation Companies (GENCOs), Transmission Companies (TRANSCOs), and Distribution Companies (DISCOs) [2]. The deregulation of power sector provides a fair competition among producers as well as consumers. Unbundling of these utilities primarily focuses on improving system efficiency, cost minimization by introducing more choices to the utilities by developing competitive markets and, better service to the electrical consumers [3].

In deregulated paradigm, the market existing between suppliers (GENCOs) and retailers (DISCOs) is called the wholesale marketplace. An ISO as an independent authority is appointed for the creation of the set of rules for ensuring sufficient control over producers and consumers for maintaining security and reliability of the electrical system while maximizing market efficiency. The GENCOs sell their energy either through long-term bilateral contracts with DISCOs or by bidding in STM operated by the ISO [4]. The basic bidding structure in STM is shown in Fig. 1.

Substantial unbundling of products and services is to be expected under restructuring process. Surely electricity provided at different times will be treated differently. It also raises the issue of AS that could be separated or bundled depending on the economics of supply and the nature of customer demand [5]. AS has become an important issue because they are necessary for the reliable and secure operation of a power system. It is essential to procure these

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Nomenclature:

Abbreviations

AC	Available Capacity
AS	Ancillary Services
AEMO	Australian Energy Market Operator
ARC	Available Reserve Capacity
ASM	Ancillary Services Market
CAISO	California Independent System Operator
CBM	Cross-Border Balancing Market
CEM	Competitive Electricity Market
CPP	Conventional Power Plants
CSP	Concentrated Solar Power
DAM	Day Ahead Market
DAEM	Day Ahead Energy Market
DARM	Day Ahead Reserve Market
DISCOs	Distribution Companies
ERCOT	Electric Reliability Council of Texas
EM	Energy Market
ESS	Energy Storage Scheme
FD	Firm Demand
FM	Forward Market
GENCOs	Generation Companies
IDM	Intra Day Market
IDEM	Intra Day Energy Market
IDRM	Intra Day Reserve Market
ISO	Independent System Operator
LMP	Locational Marginal Price
MW	Mega Watt
MWh	Mega Watt-hour
NFD	Non-Firm Demand
OF	Objective Function
OEM	Ontario Electricity Market
OPF	Optimal Power Flow
OR	Operating Reserve
PAB	Pay-As-Bid
PC	Procurement Cost
PEV	Plug-in Electric Vehicle
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PVP	Photo-Voltaic Plant
RES	Renewable Energy Source
RPP	Renewable Power Producer
RM	Reserve Market
RR	Ramp Rate
RT	Real Time
RTM	Real Time Market
RTEM	Real Time Energy Market
RTRM	Real Time Reserve Market
SB	Social Benefit
STM	Short Term Market
TRANSCOs	Transmission Companies
VIU	Vertical Integrated Utilities
VPP	Virtual Power Producer
WPP	Wind Power Plant

Symbols

AC_i	Available capacity of i^{th} GENCO
ARC_i	Available reserve capacity of i^{th} GENCO
E_i	Quantity of energy accepted in EM by i^{th} GENCO
E_{gi}^{j}	Quantity of energy offered in EM by i^{th} GENCO
E_{NFDi}^{k}	Quantity of energy bid in EM by i^{th} NFD
E_L	Energy requirement
E_{Losses}	Energy losses in EM
EP_{gi}	Energy payment by the ISO to the i^{th} GENCO
EP_{NFDi}	Energy payment received by the ISO from the i^{th} NFD
$g(V, \varphi)$	Power flow vectors
$MVAf_{ij}^{max}$	Maximum rating of transmission line connected between bus i and j
N_g	Total number of GENCOs
N_{FD}	Total number of Firm Demand
N_{NFD}	Total number of Non-Firm Demands
P_{gi}	Real power generation at PV bus i
P_{gi}^{min}	Minimum value of real power generation allowed at PV bus i
P_{gi}^{max}	Maximum value of real power generation allowed at PV bus i
P_i	Calculated real powers for PQ bus i
P_i^{net}	Specified real power for PQ bus i
P_m	Calculated real power for PV bus$m$
P_m^{net}	Specified real power for PV bus$m$
PE_{gi}^{j}	Price of energy offered in EM by i^{th} GENCO
PE_{NFDi}^{k}	Price of energy bid in EM by i^{th} NFD
PR_{gi}^{l}	Price of reserve offered in RM by i^{th} GENCO
R_{gi}^{l}	Quantity of reserve capacity offered in RM by i^{th} GENCO
Q_{gi}	Reactive power generation at PV bus i
Q_{gi}^{min}	Minimum & maximum value of reactive power generation allowed at PV bus i
Q_{gi}^{max}	Maximum value of reactive power generation allowed at PV bus i
Q_i	Calculated reactive powers for PQ bus i
Q_i^{net}	Specified reactive power for PQ bus$i$
R_i	Quantity of reserve accepted in RM by i^{th} GENCO
R_L	Reserve requirement
R_{Losses}	Reserve losses in RM
RR_i	Ramp rate offered by i^{th} GENCO
V	Voltage magnitude
V_i	Value of voltage magnitude of each PQ bus
V_i^{min}	Minimum value of voltage magnitude of each PQ buses
V_i^{max}	Maximum value of voltage magnitude of each PQ buses
Φ	Phase angle
φ_i	Value of voltage angle at bus i
φ_i^{min}	Minimum allowed value of voltage angle at bus i
φ_i^{max}	Maximum allowed value of voltage angle at bus i
λ_i	Locational marginal price at bus i
τ	Specific response time for reserve
ϕ	Penalty Factor

services in order to maintain required generation-demand balance and to guarantee the security of the supply. Frequency control, load following, operating reserves, voltage regulation, black-start services, etc. are considered as main AS in almost every country [6,7].

Under this regime, ISO has to procure these services from AS providers as these are no longer be treated as an integral part of the system. It is the matter of discussion and market structure about how to obtain and paid these services [8]. Our attention in this paper is limited to procurement of OR, which is a measure of GENCOs ability to increase their output under contingencies like unscheduled generation outages or sudden unexpected load variation, as one of the important AS [9]. Establishing an efficient

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