



## An international experience of technical and economic aspects of ancillary services in deregulated power industry: Lessons for emerging BRIC electricity markets



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### ABSTRACT

An introduction of competition in electricity markets and the substantial growth in the capacity of transactions significantly complicates the task of sustaining security and dependability of an electrical arrangement. This responsibility is dedicated to Ancillary Services (AS) that, in perspective to market liberalization, is the accountability of the System Operators (SO) to secure the requisite level of quality and safety. In the liberalized environment, AS are disaggregated from the energy generation, and can be obligated or compensated under market processes. SO seeks specific ways to define, procure and implement such services by managing active power for adjusting the frequency and reactive power for sustaining sufficient voltage profile throughout the arrangement. A comprehensive analysis of several techno-economical aspects of AS in liberalized electricity markets of a developed economy and emerging economies has been reviewed in this work. While attending the

**Abbreviations:** ABT, Availability Based Tariff; ACP, Area Clearing Price; AGC, Automatic Generation Control; ALR, Automatic Load Rejection; APFC, Assigned Primary Frequency Control; APR, Active Power Reserves; AS, Ancillary Services; ASFC, Automatic Secondary Frequency Control; ASM, Ancillary Service Market; ASMP, Ancillary Service Marginal Prices; ASP, Ancillary Services Providers; AVC, Automatic Voltage Control; BA, Balancing Authority; BAS, Basic Ancillary Services; BESS, Battery-based Energy Storage Scheme; BM, Balancing Market; BPR, Basic Peak Regulation; BRIC, Brazil, Russia, India, and China; BRPR, Basic Reactive Power Regulation; BS, Black Start; BSAS, Black Start Ancillary Services; BSCS, Black Start Capability Services; BSS, Black Start Service; CAS, Compensated Ancillary Services; CCA, Competitive Capacity Auctions; CCM, Co-optimized Commitment Mechanism; CCEE, Chamber of Electric Energy Trade; CCPP, Combined Cycle Power Plant; CERC, Central Electricity Regulatory Commission; CM, Capacity Market; CER, Conventional Energy Resources; CLPIPL, China Light and Power India Private Limited; CPR, Compensable Peak Regulation; CR, Contingency Reserves; CRAF, Contingency Reserve Adjustment Factor; CRPR, Compensable Reactive Power Regulation; CSP, Concentrated Solar Power; CWEM, Competitive Wholesale Electricity Market; DA, Day Ahead; DAEM, Day Ahead Energy Market; DAM, Day Ahead Markets; DA-RUC, Day Ahead Reliability Unit Commitment; DASR, Day Ahead Scheduling Reserve; DR, Demand Resources/Response; DSR, Demand Side Resources; ED, Economic Dispatch; EV, Electric Drive Vehicles; FCB, Fast Cut Back; FCM, Forward Capacity Market; FERC, Federal Electricity Regulatory Commission; FGMO, Free Governor Mode of Operation; FM, Forward Markets; FR, Frequency Regulation; FRAS, Frequency Regulation Ancillary Services; FSAS, Frequency Support Ancillary Services; FTR, Financial Transmission Rights; GGR, Generator Governor Response; GHG, Green House Gas; GIPCL, Gujarat Industries Power Company Limited; HAM, Hour-Ahead Markets; HEP, Hydro Electric Plant; HPS, Hydro Power Station; JOD, Joint Optimization Dispatch; IDM, Intra Day Markets; IEGC, Indian Electricity Grid Code; IEX, Indian Energy Exchange; ISTS, Inter State Transmission System; JOD, Joint Optimization Dispatch; LF, Load Following; LFC, Load Frequency Control; LMP, Locational Marginal Price; LTA, Long Term Agreements; LTC, Load Tap Changers; MCP, Market Clearing Price; MCPE, Market Clearing Prices for Energy; MPT, Market Place Timelines; MO, Market Operator; MOD, Merit-Order Dispatch; M-VCAS, Mobile Voltage Control Ancillary Services; NBS, Non-Black Start; NEP, National Electricity Policy; NERC, North American Electric Reliability Corporation; NERC-CPC, NERC Control Performance Criteria; NLDC, National Load Dispatch Centre; NSR, Non Spinning/Synchronized Reserve; NTPC, National Thermal Power Corporation; OR, Operating Reserve; ONS, Operator of the National Electricity System; PEV, Plug-in Electric-drive Vehicles; PFC, Primary Frequency Control; PFR, Primary Frequency Regulation; PGL, Peak Generator Load; PLF, Plant Load Factor; PR, Primary Reserve; PSESS, Pumped-Storage based Energy Storage Scheme; PSR, Power System Restoration; PV, Photo-Voltaic; PX, Power Exchanges; PXIL, Power Exchange India Limited; QR, Quaternary Reserve; RBA, Rational Buyer's Algorithm; RES, Renewable Energy Sources; RGPPL, Ratnagiri Gas and Power Private Limited; RIPS, Regulation Interval Performance Score; RLDC, Regional Load Dispatch Centre; RPC, Regional Power Committees; RPP, Renewable Power Producers; RPS, Renewable Portfolio Standard; RPSS, Reactive Power Support Services; RR, Regulation/Replacement Reserves; MPT, Market Place Timelines; RSS, Reactive Support Service; RT-LMP, Real Time Locational Marginal Price; RTC, Real Time Commitment; RTD, Real Time Dispatch; RTM, Real Time Market; RTO, Regional Transmission Operator; SC, Scheduling Coordinators; SCED, Security Constrained Economic Dispatch; SCUC, Security Constrained Unit Commitment; SD, Sequential Dispatch; SO, System Operators; SP, System Producers; SPP, Southwest Power Pool; SLDC, State Load Dispatch Centre; SR, Spinning/Synchronized Reserves; NERC-CPC, NERC Control Performance Criteria; SRC, Spinning Reserve Capacity; SERC, State Electricity Regulatory Commission; TAM, Term Ahead-Market; TAFC, Three-year Ahead Forward Capacity; TFC, Tertiary Frequency Control; TMNSR, Ten Minute Non-Synchronized/Non-Spinning Reserve; TMOR, Thirty Minute Operating Reserve; TMRR, Thirty Minute Replacement Reserves; TMSR, Ten Minute Synchronized/Spinning Reserve; TR, Tertiary Reserve; UCTE, Union for the Co-ordination of Transmission of Electricity; UI, Unscheduled Interchange; URS, Un-Requisitioned Surplus; US, United States; VCAS, Voltage Control AS; VCSS, Voltage Control Support Services; VIS, Vertical Integrated Systems; VS, Voltage Support; VSS, Voltage Support Service; WEM, Wholesale Electricity Market; WSCC, Western Systems Coordinating Council

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wide range of AS, the aim is to provide the promising knowledge of individual service by comparing different AS markets that exists worldwide, showing similarities and conflicts between various market models. Apart from conventional providers of AS, Renewable Energy Sources (RES) in several liberalized electricity markets seem to be a good provider of AS along with energy in order to maximize their revenue from these marketplaces. In addition to their types and definition, participation, contracting approach, selection of offers, dispatch criterion along with renewable energy participation in various electricity markets has been discussed.

## 1. Introduction

One of the primary concerns in the reformation of the electrical industry that has been received an increased attention is the awareness regarding the dependability of the electrical supply. With the large integration of RES, such as the wind and Photo-Voltaic (PV), the electrical power system is facing the degradation of frequency response. The major reasons for the frequency degradation can be summarized due to the following reasons: first, the cheap and clean, renewable energy is replacing the conventional fossil-fuel based generation. Secondly, these variable resources are extremely reliant on the weather condition, therefore, is highly uncertain and intermittent [1].

With the introduction of RES in the liberalized electricity markets and the substantial growth in the content of electrical transactions greatly complicates the job of sustaining security and dependability of an electrical arrangement. To keep a necessary supply-demand equilibrium, some sort of services are required to support the transactions from the manufacturer to the user while maintaining reliability and assuring the requisite level of quality of supply [2]. This duty is dedicated to AS that, in perspective to market liberalization, are the obligation of the SO to procure the desired service to secure the requisite level of quality and safety. These are simply classified into frequency control services, voltage control services and emergency services and are considered as main AS in almost every electricity market worldwide.

Earlier under vertical integrated systems, AS have always been bundled with the electric generation. Due to the liberalization of the power sector, the relevance of these services is recognized as one of the important issues that need to be handled efficiently and effectively. Depending upon the structure of the market and permission provided to the SO, these services is procured as obligated service or can be compensated under market-driven mechanisms [3]. The services which are procured mainly through the market-driven mechanisms are dispatched on the basis of some market settlement approaches. SO typically administers several markets that include energy and several classes of AS [4]. Referable to the restructuring of the power industry, new participants have emerged to contend in the electricity market and to offer energy and different types of AS.

Traditionally, SO tries to reduce the overall price of generation by involving unit commitment in power system operation. Due to restructuring of the electricity sector, the SO tries to increase social welfare of both generation utilities as well as consumers. Now, similar to Conventional Energy Resources (CER), Renewable Power Producers (RPPs) can take part in the energy as well as AS markets in order to maximize their net income [5]. Auctions for RES are gaining popularity around the world in both energy and AS markets due to their potential as a more cost-effective mechanism for the government. These resources are also capable of providing various types of AS due to their ability to respond at a faster rate than conventional generators [6]. In some electricity markets, the participation of RES in energy and AS markets is restricted and in some, they are allowed.

Strong concerns about the worldwide heating and energy crisis effects have led to the necessity of an extensive use of Electric-drive Vehicles (EV) in electricity markets for base load, peak force as well as storage for RES. In AS markets, EV is well suited to provide regulation services [7]. Plug-in Electric-drive Vehicles (PEVs) are advantageous compared to classical generators in energy and regulation markets.

These PEVs have faster reaction to SO requests in real-time, temporary high power, low initial and standby costs per kWh [8]

Apart from RES, technology like Energy Storage Systems (ESS) has been used widely in several electricity markets. These are mainly used for the purpose of load following, surplus power absorption, peaking power and as a standby reserve [9]. With an increase in the RE generation, ESS will ultimately overcome the ability of CER to compensate RE variability, and required to store the electricity generated by the RES for later use. The great quantities of RES to be appended to the country's energy mix to foster the goals of reducing GHG emissions and increasing energy security. A wide range of ES technologies currently exists, each with its own advantages, disadvantages, applications, constraints, and potential [10].

Due to the problems imposed by the RES on security and reliability of the power system, ESS with batteries shows a promising solution for proving energy and AS [11]. In most of the European electricity markets, Operating Reserves (OR) are traded via separate auction market with explicit regulations, which enable the Battery-based ESS (BESS) to enter in AS markets. Germany considers grid connected BESS techniques to provide several kinds of AS as an alternative to CER [12]. By optimal scheduling of microgrid in context to local level management and net-load variation mitigation, SO offer various frequency based AS in several electricity markets [13].

Due to the evolution of different electricity market structures, considerable differences appear in the definitions of AS among different electricity markets. These conflicts are the root of creating some ambiguity in understanding and defining particular service. Recent investigations of different markets help to reduce this ambiguity by setting up a background that can provide several definitions of AS [14]. For the sake of clearness and comprehensiveness, the aim of this paper is twofold. Initially, it centers on the definition and features of the different AS markets. Later, it offers a detailed analysis of different procurement techniques that are employed in the various markets of developed and emerging developing electricity markets.

Section 2 provides a general characteristics of various types of AS. Section 3 describes the functioning of the AS markets in the United States (US) as developed electricity markets, whereas BRIC nations (emerging economies of four countries, viz Brazil, Russia, India, and China) as developing electricity markets. Section 4 provides the operation of different AS like frequency regulation, load following, operating reserves, voltage control and system restoration in the selected regions. Further comparative analysis has been carried out in Section 5. Finally, in Section 6, the main conclusions of the study are inferred.

## 2. General description of AS

AS has been identified in a different manner depending on the structure and regulatory framework of the market from which they are carried out. In the present section, the general description of the most common type of AS has been discussed. The work concentrates on the social system, and the key concepts associated with each of them. In a simpler way, the resource-based AS helps us to group them into frequency control services (like regulation, load following, operating reserves), voltage control services (through reactive power support) and emergency services (by black-start services), as shown in Fig. 1.

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