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Effect of Stochastic Variables on Balancing Mechanism

Ivan Pavić[1,*], Matej Krpan[1], Igor Kuzle[1] and Yongqian Liu[2]
[1]University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb, Croatia
[2]School of Renewable Energy, North China Electric Power University, Beijing 102206, China
[*]Corresponding author

Abstract—**In the eve of power system decarbonization, the balancing mechanisms are becoming crucial to maintain continuous operation of the system. The stochastic nature of wind and solar units requests more balancing energy and it affects prices on both energy and balancing markets. This paper will try to address correlation between stochastic system variables and balancing energy volumes and prices. System variables observed are: consumption, wind and solar generation, net consumption and net consumption error.**

Keywords—power system balancing; renewable energy sources; balancing market; ancillary services; active reserves

I. INTRODUCTION

European power systems are experiencing tremendous transformation from carbon-based to decarbonized generation. It means integration of high number of Variable Renewable Energy Sources (VRES, in this paper wind and solar), often distributed on lower voltages, along with decommission of conventional centralized fossil or nuclear fueled thermal power plants. In 2017, the VRES capacity increased by 7.5% related to the end of 2016, and the total electricity produced in 2017 by VRES was around 7.5%. Some countries reached high VRES generation share, e.g. Denmark's share of VRES generation in 2017 was higher than 55% [1]. The shift introduces low-marginal cost generation units (often wind and solar powered) and disbands market price marginal units (often coal or gas powered). In theory, it means lower wholesale electricity prices due to translation of aggregated generation cost curve to the right on generation-load market clearing graph. Power systems still operate in a way that conventional units provide balancing between generation and load. Decommission of conventional units consequently leads to deficiency of balancing capability within the system [2].

New VRES units depend on variable and uncertain primary energy source which bounds their controllability and prevents them in balancing services provision. Possible balancing services provision from the VRES is possible only through wind or solar energy curtailment but it is an activity that all governments wants to mitigate. The above-mentioned lack of flexibility in power system created business opportunity for new technologies to enter the already complex power system playground. First to mention is the rise of Battery Energy Storage Systems (BESS) which see opportunity in fast balancing services such as frequency regulation and reserves among other services [3], [4], [5]. The other technology is Demand Response (DR) relating to changes in planned demand in order to provide balancing to power system [6], [7]. Main function of energy storage is to provide flexibility and to use volatility of power system variables such as Day-Ahead Market (DAM) or Balancing Market (BM) prices. Interesting technology with high potential in power system balancing are Electric Vehicles as they can be seen as both DR technology (smart unidirectional charging) or BESS technology (smart bidirectional charging/discharging), more details in papers [8], [9], and [10].

DR, EVs are small in both power and energy regarding the conventional generating units and they need an intermediary to be able to participate into balancing services provision. New entity is named aggregator (of DR or EVs) and its function is to represent them on any kind of flexibility markets. New entities and new technologies require new design of power system operational planning in order to be able to participate in balancing services provision. European power system operators have begun redesigning the operational planning scheme almost a decade ago with several goals of which the most profound are: penalization of imbalances caused by individual market players, opening balancing market to new technologies, decreasing the balancing dependency on centralized power plants, initiating the cross-border balancing, increasing the balancing regions, reducing the need of upfront capacity reservation etc. As an example of novel designs of power system balancing schemes, operators of Scandinavian region [11], Germany [12], UK [13], Hungary [14] or France [15] could be highlighted. This paper will go through French Power System operational planning as one of the most developed designs suitable for new technologies and entities.

II. FRENCH POWER SYSTEM OPERATOR – GENERAL FACTS

Transmission System Operator (TSO) in France is RTE (French *Réseau de Transport d'Électricité*) and it has the central role in transmission infrastructure handling, balancing supply and demand, designing market tools and providing the economical, reliable and clean access to power supply to its customers. Total consumption in 2017 was around 482 TWh where the largest sector is residential (36%), followed by business (26%), heavy industry (17%), enterprises (17%) and professionals (10%). Consumption peak of 94 GW happened at 07:00 PM on Friday 20. January during cold spell. On the other hand, the demand was the lowest in 2017 on Sunday 13 August when it fell to 30.2 GW. Interesting to note is that power demand in France is very sensitive to temperatures (electric heating) and in winter it increases by 2.4 MW per degree Celsius. Total generation capacity at the end of 2017. was around 130 GW of which the nuclear takes the highest share (48.3%), followed by hydro (19.5%), fossil (14.5%), wind (10.4%), solar (5.9%) and bioenergy (1.5%). Total energy produced in France in 2017. was around 530 TWh where nuclear takes the highest share (71.6%), followed by fossil-fired (10.3%), hydro (10.1%), wind (4.5%), solar (1.7%) and bioenergy (1.7%). Total installed wind power at the end of 2017 was 13.559 MW where newly added capacity in 2017 was 1.797 MW. Record output was 11.075 MW at 30 December 2017 and wind covered in average 5% of demand. Total installed solar power capacity at the end of 2017. was 7,017 MW where newly added capacity in 2017 was 887 MW. Record output was 5.646 MW on 20 April 2017 at 2 PM, and solar covered in average 2% of demand. More details could be found in 2017 yearly report by RTE [16].

III. RTE Balancing Mechanism

In order to balance the grid RTE must equalize supply and demand in its power system. The system is balanced using several mechanisms. We can separate those mechanisms into three categories: imbalance settlement, balancing market and reserves. Each grid user must be a part of balance-responsible entity who acts as a mediatory between users and RTE for issues related to balancing. Each balance-responsible entity (BRE) must maintain the balance between its planned market position and real-time realizations. If there is positive imbalance meaning that BRE injects more than planned, BRE is paid by RTE for the additional injected energy. If BRE extracts more than planned, i.e. the imbalance is negative, than BRE pays to RTE for overextracted energy. The price by which they pay or get paid depends on balance position of total system as shown in Figure 1. The idea behind the Imbalance settlement mechanism is to encourage BRE and their users to keep the balance in each time step.

If they do not keep the balance or some failure in the system happens, the imbalance occurs and the RTE must activate balance service providers (BSR) to inject/extract more/less energy to/from the system than planned. Two mechanisms can be used for balancing: balancing mechanism or activation of reserves. Balancing mechanism is a market with gate closure close to real-time (gate closure is two hours before real-time) where users submit bids for upward or downward balancing energy if they have spare/unused capacity (capacity not sold on energy or reserve market). RTE collects all bids for specific hour and calls, when needed, the users with the lowest price bids. The price is paid on pay-as-bid principle.

If the imbalances are too fast to be balanced through balancing mechanism or there are insufficient offers on balancing mechanism, the reserves are used. There are four reserves defined by RTE: frequency containment reserve (FCR), automatic frequency restoration reserve (aFRR), manual frequency restoration reserve (mFRR), and Replacement Reserve (RR). First two are considered as frequency ancillary services, while the other two are considered as reserves. FCR is carried out with cross border auctions on platform [17], while the aFRR is regulated as obligation and priced with 18 EUR/MWh. Both mFRR and RR are obtained through yearly tenders. All technologies can participate on all markets.

IMBALANCE PRICE FORMATION

	Upward balancing trend	Downward balancing trend
Positive imbalance (I > E) RTE usually remunerates the BR	Epex spot price	WAPd / (1+k)*
Negative imbalance (I < E) The BR remunerates RTE	WAPu x (1+k)**	Epex spot price

*Upper limit: Epex spot price. **The Epex spot price is a floor price. k: weighting coefficient fixed at 5% as of 1st January 2009. Current value is published on the RTE website.

FIGURE I. IMBALANCE PRICE FORMATION

The day-ahead market is a market with physical delivery requirements, and it is the main market in European power systems. In France electricity exchange called EPEX operates the DAM. In next chapter, it will be shown how different system variables impact prices and volumes on imbalance settlement, balancing market or reserve market and activation.

IV. Effect Of System Variables On Balancing Prices And Volumes

In this section, five system variables will be observed in correlation to different prices and volumes engaged in balancing activities in France. Observed system variables are: consumption, wind power, PV power, Net Consumption (difference between consumption and wind + PV generation), and Error between forecasted day ahead and realized net consumption. The data sets used are hourly averages for year-round data in French power system for 2018. For reserves, only FCR was displayed in the table below. The cells with correlation higher then 0,3 are colored in red.

TABLE I. CORRELATION BETWEEN VARIABLES

System variables	Correlation	Balancing v.	System variables	Correlation	Balancing v.
Cons. Real.	0,291483	DAM Price	Cons. Real	0,360629	BM Av. Price Up
Wind Real.	-0,15258	DAM Price	Wind Real.	-0,04161	BM Av. Price Up
PV Real.	0,040265	DAM Price	PV Real.	0,001411	BM Av. Price Up
Net Real.	0,32846	DAM Price	Net Real.	0,384631	BM Av. Price Up
Error J-1	0,220202	DAM Price	Error J-1	0,132964	BM Av. Price Up
Cons. Real.	0,371123	ISP Price UP	Cons. Real.	0,317889	BM Av. Price Dn
Wind Real.	-0,05643	ISP Price UP	Wind Real.	-0,13892	BM Av. Price Dn
PV Real.	0,031091	ISP Price UP	PV Real.	0,068055	BM Av. Price Dn
Net Real.	0,394537	ISP Price UP	Net Real.	0,349805	BM Av. Price Dn
Error J-1	0,045793	ISP Price UP	Error J-1	0,150222	BM Av. Price Dn
Cons. Real.	0,371269	ISP Price Dn	Cons. Real.	0,095568	FCR Vol. Up
Wind Real.	-0,05602	ISP Price Dn	Wind Real.	0,119551	FCR Vol. Up
PV Real.	0,031134	ISP Price Dn	PV Real.	-0,05527	FCR Vol. Up
Net Real.	0,394605	ISP Price Dn	Net Real.	0,084298	FCR Vol. Up
Error J-1	0,045488	ISP Price Dn	Error J-1	-0,07618	FCR Vol. Up
Cons. Real.	-0,1302	ISP Vol.	Cons. Real.	0,289937	FCR Price Up
Wind Real.	-0,05491	ISP Vol.	Wind Real.	-0,1564	FCR Price Up
PV Real.	-0,01226	ISP Vol.	PV Real.	0,039277	FCR Price Up
Net Real.	-0,12398	ISP Vol.	Net Real.	0,327701	FCR Price Up
Error J-1	0,353723	ISP Vol.	Error J-1	0,21195	FCR Price Up
Cons. Real.	0,31259	BM Vol. Up	Cons. Real.	-0,07267	FCR Vol. Dn
Wind Real.	0,1562	BM Vol. Up	Wind Real.	0,098185	FCR Vol. Dn
PV Real.	-0,10592	BM Vol. Up	PV Real.	-0,25977	FCR Vol. Dn
Net Real.	0,31074	BM Vol. Up	Net Real.	-0,06064	FCR Vol. Dn
Error J-1	-0,17577	BM Vol. Up	Error J-1	0,045853	FCR Vol. Dn
Cons. Real.	-0,05713	BM Vol. Dn	Cons. Real.	0,289937	FCR Price Dn
Wind Real.	0,053536	BM Vol. Dn	Wind Real.	-0,1564	FCR Price Dn
PV Real.	-0,07705	BM Vol. Dn	PV Real.	0,039277	FCR Price Dn
Net Real.	-0,05982	BM Vol. Dn	Net Real.	0,327701	FCR Price Dn
Error J-1	0,196494	BM Vol. Dn	Error J-1	0,21195	FCR Price Dn

Several observations could be seen. First, all prices observed have slight correlation with consumption and net consumption. The reason why the correlation is not of a higher value is because we didn't take into account other variables such as fuel costs, available transfer capacity, import/exports, consumption and methodological conditions in neighboring countries, etc. Net consumption always has a higher correlation then consumption alone meaning that wind and solar have an effect on price formation on all observed markets. Since their share is still very small, the effect is also not significant, but the trend exists and with higher uptake of renewables their effect will be much higher. The volumes have different correlation than prices. Interesting to see is that volume of imbalances shows slight correlation with error of net consumption. Of other volumes, only volume of balancing mechanism for upward balancing is showing similar correlation as prices.

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