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Towards a Romanian power system based on high renewables penetration – the case of bess usage

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Abstract. In this paper we present the problem of adapting the electricity generation sector towards achieving 100% CO_2 free until 2050. Starting from the actual generation-load records in Romania, we estimate the necessary wind and photovoltaic power to be installed for replacing the fossil fuel power plants. The analysis has revealed that energy storage systems are required to cover the night load and to control the power exchange with neighbor countries. Based on the installed power estimations, we have estimated the needed financial investments.

Keywords: renewable energy sources, battery storage energy systems, power systems.

1. Introduction

Affordable electricity storage systems have been sought for more than 100 years, from the very beginning of the electrical energy ecosystems. Until now, bulk storage through pumped hydro units, hydraulic power plants with big lakes, and thermal plants using the fuel in the appropriate moment have been the most present and effective solutions to maintain the balance between generation and load. However, all these solutions do not store electrical energy, but they are capable of handling the primary source in such a way to maintain live the paradigm "Electrical Energy needs to be consumed at the instant of production". This happens also because classic batteries, which exist also for more than 100 years, have been always expensive and unpractical for applications dealing with high power and energy.

Small steps have been constantly done, without being available as information for the wide-world public, while the most of the specialists underestimated the potential for future development in the power system domain. With the advent of the IT technology, namely the mobile gadgets, higher requirements have been needed for better batteries. Li-Ion batteries were the first used for laptops, then in emerging telephone market which progressively turned into smartphones, meaning telephone as a computer. Due to this IT-related market, Li-Ion

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battery price has been reduced 7 times in a period of 15 years, and in the last 5 years, when EVs and power systems applications started to be appealing new areas, the price has been again reduced 4 times. The prices has therefore decreased by around 30 times since the '90s, which made room for new opportunities. The so called battery energy storage systems (BESS) became reality. The year 2017 is a key milestone for a technology shift in both power systems and electrical vehicles and has been coined already as being the "year of storage boom". The recent success in both domains shows clearly that energy storage is a game changer and that new horizons need to be scrutinized. In this context, the paper makes an assessment on the feasibility of a dramatic increase the renewables production in Romania, in conditions of targeting 100% CO_2 free electrical energy and transportation.

2. Assessments on Romanian power system

By analyzing the energy production and consumption recorded for the Romanian power system in selected days and weeks [1], we show that storage resources can mitigate situations with 100% CO_2 free. This analysis has been achieved by simulating through scaling the production and consumption based on new scenarios where technologies with CO_2 emissions have been phased out, by also maintaining a similar power exchange with neighbors, in order to avoid network reinforcement and to improve regional auto-consumption. Figure 1 shows the energy mix after phasing out coal and gas-based energy production in a selected day and by increasing the PV and wind-based production until the daily total consumption is equal with the energy production.

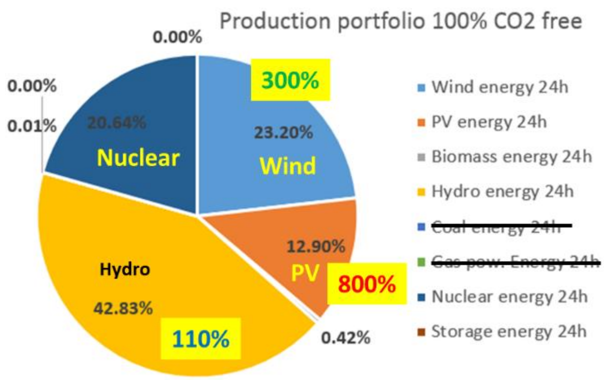

Fig. 1. Energy mix for the 100% CO_2 free scenario.

Considering the actual energy mix in Romania, in a specific day with 64% share of generation from hydro and nuclear, the share of generation from wind and PV sources of up to 36% can be needed. In such situation, an increase by 800% of the PV parks and by 300% of the wind parks will allow supporting such RES generation portfolio.

Based on the energy mix presented in Figure 1, a hypothetic generation profile was simulated for a specific day recorded in the Romanian power system, namely 08.06.2017, by scaling the generation curves (Fig. 2). Therefore, the PV generation was multiplied by 8, the wind generation was multiplied by 4, while the generation from nuclear units have been maintained constant.

It can be seen that the load does not match the generation over the whole day, the highest mismatch occurring during the middle of the day when a difference of nearly 4 GW is observed. The mismatch results because, as estimated, the load will not increase by more than 10%, and the difference will be additional power exchange with the neighbor countries.

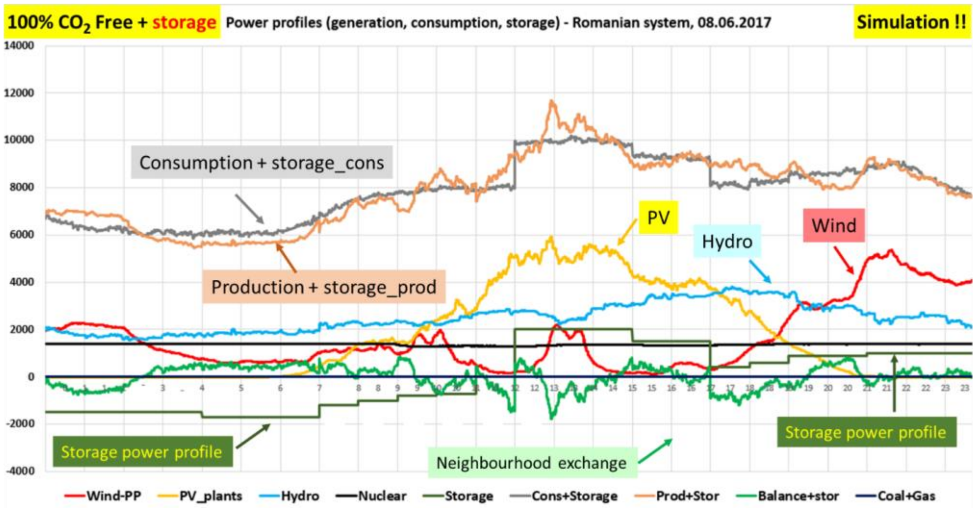

Fig. 3. Simulation of the generation, load and storage curves
over the above-mentioned day in June 2016.

The simulation shows that the Romanian power system exchanges 16 GWh with the neighbors, which behaves as a giant battery, absorbing energy during some periods and generating it back during other periods. The power exchange with other countries need to be reduced at acceptable levels which do not require strong reinforcements or even keeps the today capacity. Investments in new lines are therefore avoided, which is good for several reasons, such as environmental impact and public acceptance, subject which is increasingly sensitive in the last period.

In order to maximize the self-consumption inside the Romanian power system and to reduce the risk of curtailment, if the tie-line power exchanges need to be limited due to other countries constraints, storage resources can be used. Figure 3 presents the situation from Figure 2 but with added 14.8 GWh storage resources inside the country.

With the help of the storage systems, the tie-line energy exchange is reduced to acceptable values. The maximum power can be reduced by more than two times, from 3.7 GW to only 1.7 GW. Moreover, the self-consumption increases from 91% to 97.2%, thus increasing resilience and system stability through better local / regional balance. Note that, in both situations, the power exchange is also automatically reduced through the traditional secondary f-P control and through the engaged tertiary reserve.

Similar simulations have been made for other selected days over the year. Based on these daily examples, the level of storage needed was in the range of 35 to 45 GWh, in order to mitigate different periods of generation and load. Table 1 shows meaningful figures for selected days, in the paradigm of CO2 free scenario, as follows: Day 1 (D1, 02.08.2016), Day 2 (D2, 10.09.2016), Day 3 (D3, 15.11.2016), Day 4 (D4, 17.03.2017), Day 5 (D5, 22.04.2017), Day 6 (D6, 29.05.2017).

Table 1. Generation and storage scaling factors
for six different days.

	D1	D2	D3	D4	D5	D6
Wind scaling	2.5x	2.5x	2.5x	2.5x	1.2x	2.5
Wind max. power[GW]	1.1	1.4	4.1	4.9	2.2	1.4
PV scaling	21x	15x	22x	14x	10x	12x
PV max power [GW]	10.1	10.4	5.3	7.7	7.6	9.4
Max battery energy [GWh]	40	42	19	29	26	26
Max battery power [GW]	7	7	4	4.5	4.5	4
Max power exchange [GW]	1.1	1.8	5.2	7.7	1.4	1.6
Battery Max power to Max energy ratio	3.96	4.04	3.58	3.77	3.42	2.77

Based on several days selected from a year, it appears that the storage necessary to cover selected daily needs are between 19 and 42 GWh, with 45 GWh as the optimum value to cover most of the usual situations.

Another type of analysis is to assess the necessary storage over a longer period of time, by keeping the same RES scaling over the entire period.

Figure 3 shows the evolution of the Romanian power system over a week in January 2017, in the presence of a storage resource and allowing a limited exchange of power with the neighbors.

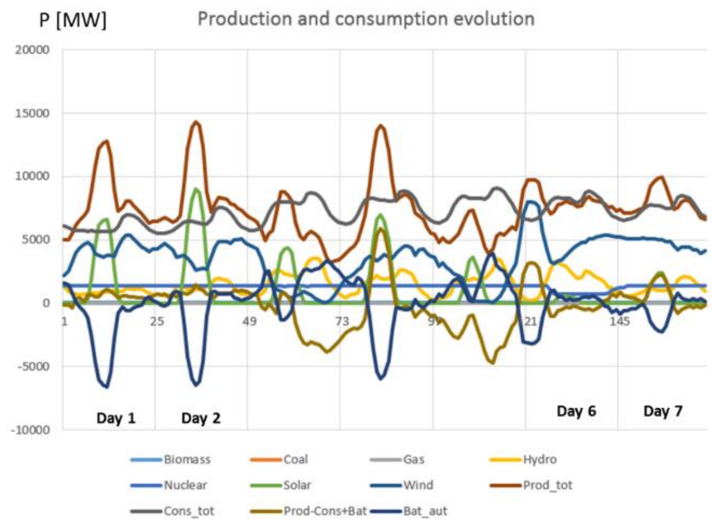

Fig. 3. Simulating the generation and load over a week in January 2016.

Figure 4 shows the evolution of the storage profile over the same week. It can be observed that in sunny days (such as Day1 and Day2 in the selected week) storage of energy over longer periods than one day (case presented before) is needed, while during cloudy days the already stored energy can be provided back into the grid.

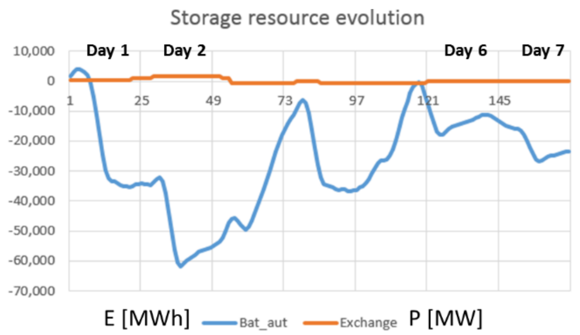

Fig. 4. Simulation of storage service for the selected week in January 2016.

Similar analysis has been made for a summer week (June 2016). For this, a storage curve as presented in Figure 5 may be needed.

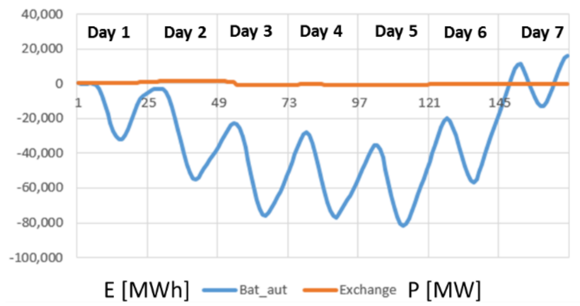

Fig. 5. Storage service simulation for a selected week in June 2016.

Based on these examples, one can see that by considering week-based scenarios, the medium term storage needed becomes higher than for the day-based scenarios presented before, respectively 60 and 80 GWh of distributed storage resources.

In order to include even more stringent situations, we conclude that up to 100 GWh of short and medium term electrical storage using BESS is appropriate for reaching 100% CO_2 free production in the Romanian situation:

- by still preserving some base production with nuclear (which can deliver up to 20% of the country needs),
- by continuing to use hydro flexibility,
- by preserving a limited energy exchange with neighbors, in the frame of today capacity,
- by scaling around 3 times the wind production capacity; this means that today 2.9 GW of installed capacity might be increased up to 8.7 GW (unfortunately most of it in the windy regions of the country, which may require network reinforcement as well as local storage to laminate the wind production evacuation).
- by scaling 15-22 times the PV generation capacity, which means 19.5-28.6 GW if taking as reference the today installed power of 1.3 GW; fortunately, this capacity can be spread all-over the country, connected to high, medium and low voltage networks, as well as at the prosumer premises, thus being able to avoid network reinforcement.

By choosing round figures for the necessary investments to reach 100% CO2 free electrical energy production we can conclude that the required effort until the 2040-2050 horizon will be:

a) 100 GWh of storage resources, to be replaced every 10 to 30 years for one cycle per day (10 years is now the normal case, 20 years is already attended in 2017 but at higher prices, 30 years can be attended in the next 5 to 10 years as well);

b) 10 GW of capacity in wind production, to be replaced after more than 25 years;

c) 30 GW of capacity in solar production, to be replaced every 25 years;

d) Additional long-term storage based on other technologies, such as hydrogen;

e) Nuclear based production as it is now may be needed to be kept operational on the same horizon, if no new disruptive technology or advancements in exiting technologies take place.

In terms of investments, a first overview may need the following investments:

- at an reachable price of 100 Euro/kWh in storage (BESS), a 10 billion Euros investment is needed; it is expected that the 100 Euro/kWh price may be reached by 2020-2022, and that in 2030 it can be reduced again, reaching 50 Euros/kWh, while the number of cycles can support a daily cycle for 20 to 30 years. Thus, a total investment based on incremental introduction of BESS at different prices may lead to a total BESS investment of 6 to 7 billion Euros;
- at a price of 1000 Euro/installed kW in wind, which also may face some reductions, e.g. to 800 Euro/kW, we may infer a total investment for the 10 GW of wind power of around 9 billion Euros;
- from the actual 1000 Euro/installed kW in PV, by extending grid-side PVs as well as community and individual PVs, combined with advanced microgrids, prosumers enforcement and hybrid / DC networks, the price may drop down to 500 Euro/KW; we may infer a total investment for the 30 GW of solar power at an average of 700 Euros/kWh (already achieved in 2017 in India, at community level PV production) of around 30 x 0.7 = 21 billion Euros.

A total of 10 + 9 + 21 = 40 billion Euros (except for the case in which the nuclear technology is still used) may be sufficient for a 100% CO_2 free production. If the goal is to achieve 100% CO_2 free by year 2040, it means that for the remaining 22 years we need an yearly average effort of 40/22 = 1.82 billion Euros.

In both timeframes, the storage (key enabler for RES) accounts for only 10/38 = 26.3% of the effort, meaning only one fourth of the investment.

Figure 6 gives the image of the financial effort share for reaching 100% CO_2 electrical energy production.

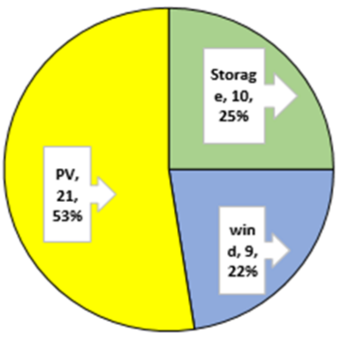

Fig. 6. Estimated share of financial efforts to reach 100% CO2 free electrical energy generation.

The breakdown of investment suggests that the higher need for simple and cost-effective solutions are needed for PV units, and thus the grid connection codes, microgrids and prosumers accommodation are mandatory for reducing the overall bill.

This is a feasible solution till year 2040 (and till more relaxed year 2050 target), thus giving good grounds for reconsidering some system organization rules, especially in the distribution networks. The paper gives also some proposal of grid evolution based on distributed storage, which can both improve the system stability, by reducing long range circulations and self-consumption, as production, storage and consumption can be managed at the consumer and/or prosumer level.

3. Conclusions

This paper gives some first views on the 100% CO_2 free production challenge from balancing point of view provided by new battery technology. It is suggested that a distributed storage cumulated resource of up to 100 GWh covers the needs for most of the daily and weekly time horizons, while long term storage technologies are still needed for covering longer time surplus or deficit of RES. Future work will address other aspects being able to refine more different details of the new trend.

References

[1] Status of National power system in real-time, http://www.transelectrica.ro/widget/web/tel/sen-harta/-/harta_WAR_SENOperareHartaportlet, accessed during 2016-2017.