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INTEGRATION OF VARIABLE ENERGY SOURCES IN ENERGY SYSTEMS

Corina Guțu-Chetrușca*, ORCID: 0000-0001-6090-4421,
Dumitru Braga, ORCID: 0000-0002-5500-2033

Technical University of Moldova, 168 Stefan cel Mare Blvd., Chisinau, Republic of Moldova
Corresponding author: Corina Guțu-Chetrușca, *Corina.gutu@tme.utm.md*

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Abstract. The main global concern in the energy sector is the substitution of fossil fuels and the mitigation of climate change - the transition to the carbon neutrality of the economy. For the power sector, the main solution for this transition is to use hydro, wind and solar energy sources, which have a high energy potential, including in the Republic of Moldova. Variable renewable energy sources, wind and solar, due to their intermittent nature have a significant impact on the power system and the quality of electricity. The necessary measures to reduce the impact of the variability of these sources are presented. The most appropriate measure would be to use pumped storage hydropower plants. The water losses from their accumulation lakes were appreciated. That constitutes approx. 1 … 2 m^3/MWh which is considerably lower than the losses from the Thermal Power Plants with steam turbines.

Keywords: *variable renewable energy sources, energy storage, water losses.*

Rezumat. Principala preocupare la nivel mondial în sectorul energetic este substituirea combustibililor fosili și atenuarea fenomenului schimbărilor climatice – tranziția către neutralitate de carbon a economiei. Pentru sectorul electroenergetic principala soluție pentru această tranziție constă în utilizarea surselor hidro, eoliene și solare de energie, care au un potențial energetic înalt, inclusiv în Republica Moldova. Sursele regenerabile variabile de energie, eoliene și solare, din cauza caracterului intermitent au impactul semnificativ asupra sistemului electroenergetic și calității energiei electrice. Sunt prezentate măsurile necesare pentru diminuarea impactului variabilității acestor surse. Măsura mai potrivită ar fi folosirea Centralelor Hidroelectrice cu Acumulare prin Pompare. S-au apreciat pierderile de apă din lacurile de acumulare ale acestora. Ele constituie cca. 1…2 m^3/MWh ceea ce este considerabil inferior pierderilor din Centralele Termoelectrice cu turbine cu abur.

Cuvinte cheie: *sursele regenerabile variabile de energie, acumularea energiei, pierderi de apă.*

Introduction

In recent years, Renewable Energy Sources (RESs) are occupying a growing important place in the global electricity mix, reaching a share of 29% by 2020 [1]. In the future, the volume of renewable energy generation will have a continuously growing trend. In the recent period, the investments in renewable energy systems had a share of around 70% of total energy investments. The installed capacity of the renewable energy systems increased by more than 256 gigawatts (GW) during the pandemic, the largest increase ever [1, 2]. The COVID-19 pandemic has had a significant impact on the power sector, with total production declining by 4%, while its production from renewable sources, which is less affected by restrictions and largely unaffected by demand, has increased worldwide in 2020, compared to 2019, by 6.3% [3]. Over the next decade, the commitments announced by governments will lead to an expansion of renewable sources, that is fast enough to keep pace with rising electricity demand and reduce the share of fossil fuels to meet electricity needs. It is estimated that the share of renewable energy sources will increase from almost 30% of global electricity generation in 2020 to about 45% in 2030 according to the Announced Pledges Scenario (APS) and could exceed 60% in the Net Zero Emissions Scenario (NZE) [4].

Recently, RESs have also increased in the Power sector of the Republic of Moldova: from 17.2 million kWh in 2015, production has increased to 81.4 million kWh in 2020, but their share in the total volume of energy is quite small - 9.6% of domestic product and less than 2% of electricity consumption per republic [5].

Depending on the primary source, electricity generated by RESs has different particulars. Although, if hydraulic, geothermal, biomass energy can be used at the necessary time and in the required quantity, so-called variable energy generated by variable renewable energy sources (VREs), as solar and wind, being intermittent and sometimes unpredictable over time, can have a negative impact on the operation of power systems. At the same time, these sources have a number of advantages. They are more environmentally friendly compared to other RESs, require less operating and maintenance costs, and as result, the cost of generated energy is lower, and has a continuous downward trend, while for other types of RES these costs increase.

The specific investments for power plants using RESs and the Levelized Cost of Energy are presented in Table 1 [6]. It is noted that the specific investments for geothermal and hydraulic energy increased significantly during the last 10 years. At the same time, the specific investments for solar PV and wind systems decreased considerably. The price of solar PV electricity is slightly higher than that of hydraulic electricity, but, given the nature of their change, the reversal of this ratio is expected. It should be noted that these prices are in a favorable ratio with those of fossil fuel energy which are in the range of 0.05 - 0.15 USD / kWh [1, 6].

Table 1

Total cost of investment in RES and levelized cost of energy produced for 2010 and 2020*

Type of renewable energy source	Total installed costs			Levelized cost of electricity		
	2020 USD/kW		Percent change	2020 USD/kWh		Percent change
	2010	2020		2010	2020	
Bioenergy	2619	2543	-3	0,076	0,076	0
Geothermal	2620	4468	71	0,049	0,071	45
Hydropower	1269	1870	47	0,038	0,044	18
Solar PV	4731	883	-81	0,381	0,057	-85
Wind (onshore**)	1971	1355	-31	0,089	0,039	-56

**After [6]; ** wind offshore and ocean systems being unavailable for the Republic of Moldova, as well concentrated solar energy requiring large installation areas are not considered.*

Being the cheapest and most competitive, VRESs - solar PV and wind, far exceed the other sources in their growth and, according to [4], will ensure about 75% of the increasing electricity demand by 2030 in the Stated Policies Scenario (STEPS) and 90% in APS. This means that the share of solar PV and wind energy in electricity balance for 2030 will increase from below 10% in 2020 to 23% in STEPS and 27% in APS. The energy generated by hydropower, bioenergy, geothermal and concentrated solar systems is expected to grow much lower by 2030 in all scenarios, as they have longer project deadlines and require favorable site conditions and resources.

Problems of variable renewable energy sources and solutions

Intermittency, variability, and unpredictability of solar and wind energy are serious challenges for the power system's operation and control, affecting its stability, reliability, flexibility, and resilience. They also cause a reduction of the load factor of the respective systems, which leads to the increase of the payback period for power plants using VRESs. For the European area, the capacity factor for wind systems is 17 ... 22%, and for PV systems 5 ... 11% [7], while for conventional power plants using fossil or renewable fuels it is 60 ... 80 %. The values of capacity factors in the conditions of the Republic of Moldova are: for PV systems - 8 ... 9%, for wind systems - 9 ... 13% [5].

According to the mentioned above, it can be concluded that the massive use of solar PV and wind systems requires alternative energy sources or other measures, such as interconnection with other power systems, hybrid generators, synergy generation - consumption, energy storage.

Alternative sources at the present stage are mainly represented by conventional power plants using fuels. The NZE scenario envisages replacing them with power plants using invariable renewable sources (hydro, bio, geothermal) and nuclear power. Connections to other systems allow to take advantage of different climatic conditions in different geographical regions and alternative sources from neighboring power systems.

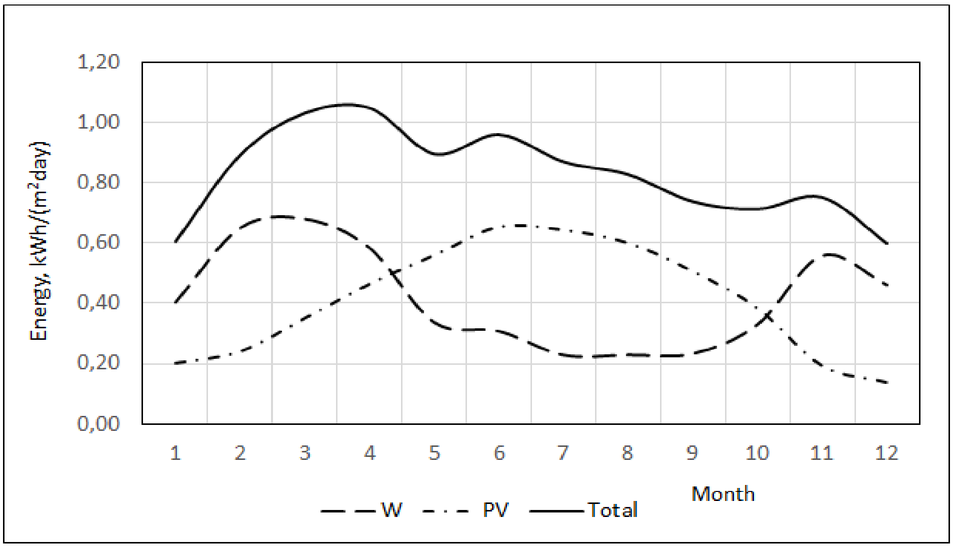

Figure 1. Operation dynamics of a hybrid PV-wind installation in climatic conditions in the central part of Republic of Moldova [8].

The PV-wind hybrid systems present a promising solution due wind and solar energy are complementary to each other, which makes this type of system generate electricity throughout the year, and in some cases, they also provide the diurnal load curve. For the climatic conditions in the center of the Republic of Moldova, this is demonstrated by the graph in Figure 1 which shows the dynamics of operation of a hybrid installation [8] The monthly production is at the level of 0.8 kWh / (m^2 day) and varies in the limits of -26.1% (in January-December) and +27.2% (in March).

Some cases of system imbalance can also be avoided by synergy between generating and consumption, or the concordance of energy production with the consumers electricity load. For example, agrovoltaic systems can be used for irrigation pumping stations. Approx. 40% of the energy can be produced by PV systems installed on 15% of their roof surface [9]. Another example is residential buildings. The energy produced by the PV systems installed on the roof in summer can be used for air conditioning, and in winter - for heat pumps. In addition, the pandemic, which introduced and developed online work and home learning, led to an increase in household energy consumption during the day, which coincided with the peak of electricity generation by PV systems [10]. Working from home has proven to be convenient for both employees and employers and is expected to remain so after the pandemic crisis is resolved. The most common method of solving the problems created by the variability of Renewable Energy Sources is the storage of electricity.

Energy storage

Energy Storage Systems (ESS) can provide safe and cost-effective answers to the problems facing power grids today - in the SMART GRID development phase that they are going through [11, 12]:

- starting the equipment after the fault, ensuring without resorting to the network for the necessary energy (cases of black-out/start or brown-out/start);
- energy storage during periods of low load and low prices and supplying consumers with energy during peak periods and higher cost;
- ensures due to the associated power electronics, the control and the fast variation of the active and reactive power, maintaining the optimal parameters of the network;
- reducing the need to provide conventional units, the ESS providing the function of "spinning reserve";
- fast provision through stored energy, at additional demand requested by the consumer;
- facilitating the integration of VRES, by storing energy when time allows and returning it when it needs to be delivered;
- storage of excess energy in case of favorable weather conditions, in conditions where there are no demands and efficiency of wind farms, photovoltaic.

Since there is no possibility to directly store electricity, a wide range of storage methods are used by converting it into other forms of energy. Possible solutions for storage systems include:

1. Mechanical storage:
   a. pumped hydro,
   b. compressed air,
   c. flywheels;
2. Electrochemical storage:
   a. batteries with internal storage (eg Pb-acid, NiCd, Li-ion),
   b. externally stored batteries,
3. Electrical storage
   a. superconducting magnetic energy storage,

b. supercapacitors (different technologies).

4. Thermal storage

a. cryogenic storage systems, liquid air energy storage (LAES)

b. molten salts.

5. Chemical storage:

a. hydrogen;

b. ammonia

and other.

The choice of the appropriate system can be made on the basis of several factors, such as required storage capacity, minimum storage period, loading and unloading conditions, available space and environment, type of compensated fluctuations, required energy density, lifespan required, the minimum number of cycles and the properties of the energy system.

Overall, the global operational energy storage capacity reached 191.1 GW in 2020, reflecting 3.4% growth year on year. The largest market was China (18.6% of the global total), which reached 35.6 GW by year's end, up 4.9% from 2019. The United States added 1.5 GW due to a record fourth quarter in the deployment of front-of-the-meter storage, to reach an estimated 23.2 GW by year's end. The European market grew 54%, adding 1.7 gigawatt-hours of storage capacity for a cumulative capacity of 5.4 GWh. In addition, 4 GW was either announced or under construction across the region. The structure of the installed power according to the technology is shown in Figure 2. Pump storage continued to present the largest part of the installed capacity, over 90%.

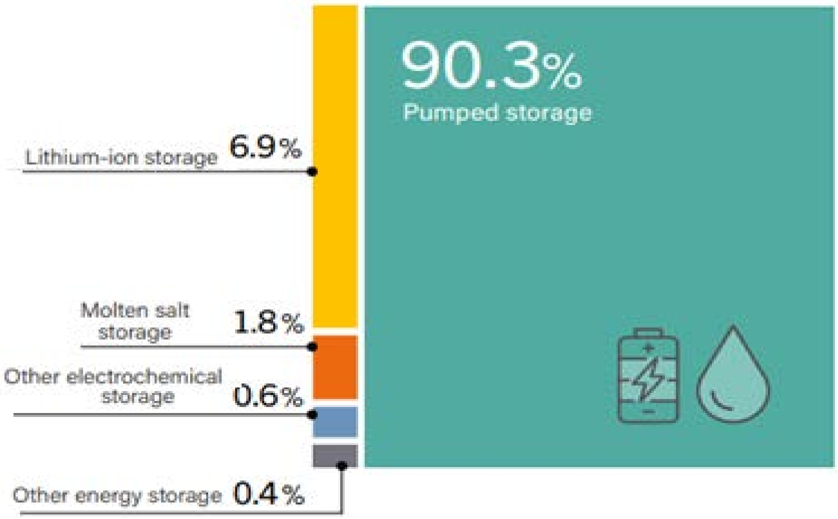

Figure 2. The installed capacity structure of global electricity storage units at the end of 2020 [1].

Pumping storage: use possibilities in the Republic of Moldova

According to [13 and 14], pumping storage is the only commercially proven technology available for the large-scale storage of energy in a power system, from which the Republic of Moldova could benefit fully. On the other hand, in the media of the republic, there is a concern that the accumulation lakes of the Pumped Storage Hydro Power Plants (PSHPP) can significantly affect the hydrological balance of the republic [15, 16, 17].

In order to assess the degree of influence of PSHPP on the hydrological regime, the calculations of water losses from the accumulation lake of a 50 MW Power Plant were performed. The characteristics of PSHPP are presented in Table 2. Load adjustment shall be provided for one day with a turbine operating time of 8 hours.

Table 2

The analyzed PSHPP characteristics

Power plant capacity, MW	50
Pumping efficiency	0,7
Generation efficiency	0,8
Day time load adjustment type	Day time
Operating time, h/day	8
Energy generation, MWh/day	400
Net fall height, m	100
Turbine water flow, m^3/s	63,71

The sizing of the storage lake is carried out, considering the useful volume equal to the amount of water required for the operation of PSHPP at nominal power during the daily operation. The calculation scheme of the lake is shown in Figure 3. The characteristics of the lake are presented in Table 3. Water losses in the lake consist mainly of evaporation losses E from the water surface and filtration F through the water-covered part of the lake cuvette. They are partially offset by atmospheric deposits D that occur during the year on the surface of the soil occupied by the lake basin.

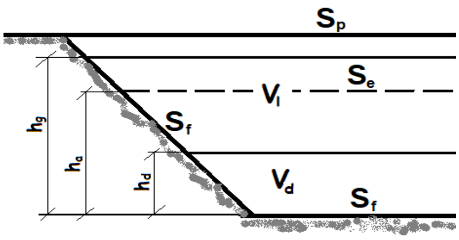

Figure 3. PSHPP reservoir calculation scheme:

V_l – live storage volume, V_d – dead storage volume, S_p - precipitation surface, S_e - evaporation surface, S_f - infiltration surface, h_g- depth of the brut gross volume, h_a- average depth, h_d- depth of the dead volume.

Table 3

Characteristics of the CHEAP accumulation lake

Volume of water consumed, Mm^3/ day	1,83
Volume of water consumed, Mm^3/ year	669,72
Quotation useful tank	0,85
Gross volume of tank, Mm^3	2,45
Talus angle, degrees	45,00
Maximum depth of tank, m	20,00
Medium depth of tank, m	16,6
Surface of deposits, m^2	122 224
Vaporization surface, m^2	115 671
Filter surface, m^2	123 610

Thus, the losses ***P*** will be determined by the formula [18, 19]:

$$P = E + F - D, \text{ m}^3/\text{year} \quad (1)$$

In turn:

$$E = S_e \cdot e; \quad (2)$$

$$F = S_f \cdot f; \quad (3)$$

$$D = S_p \cdot p. \quad (4)$$

In these formulas:

S_e is the evaporation surface;

S_f - the filtering surface, equal to the water-covered surface of the lake cuvette;

S_p - the cross-sectional area of the upper part of the cuvette;

e - Evaporation layer from the surface of the water, according to [18], for the corresponding area of RM ***e*** **=** 0.8 ... 1.0 m / year, consider ***e*** = 0.9 m / year;

f - water filtration layer in the soil, according to [19], ***f*** = 0.4 ... 1.0 m / year, consider *f* = 0.8 m / year;

p - precipitation in the territory of RM, according to [20], ***p*** = 0.49 ... 0.62 m / year, consider *p* = 0.53 m / year;

The values of the surfaces are given in Table 3. The calculations were performed for two types of CHEAP: open cycle and closed cycle. Open-cycle CHEAPs are built on the banks of large rivers, from which water is pumped into the upstream reservoir. The closed cycle CHEAP is equipped with two lakes, upstream and downstream, one of which is supplied with additional water from a smaller source.

The results of the calculations are presented in Table 4.

Table 4

Water loss values in CHEAP reservoirs

Characteristic		**Value**	
		Open cycle	**Closed cycle**
Cycle losses	m^3/day	379	757
	% from the cycle	0,021	0,041
Annual losses	m^3/year	138 213	276 427
	% from the lake volume	11,1	11,1
Specific losses	m^3/MWh	0,96	1,92

As can be seen from the table, the current losses are insignificant - hundredths of percentages, but the annual ones related to the volume of accumulated water are significant - over 11%. The specific losses, per production unit, are 0.96 m^3 / MWh and 1.92 m^3 / MWh, respectively. It should be mentioned that they are 2 ... 3 times smaller than the water losses from the cooling towers of the Thermoelectric Power Plants with steam turbines which is 2.7... 4.2 m^3 / MWh [21].

Conclusions

Power plants using variable Renewable Energy Sources, in the future, will occupy a predominant place in the production of electricity in the Republic of Moldova. Their intermittency, variability, and unpredictability will affect the stability, reliability, flexibility, and resilience of the National Power System of the Republic of Moldova. To counteract this damage, it is necessary to apply a number of main measures, including the storage of electricity. For this, the Republic of Moldova could fully benefit from the technology of accumulating electricity by pumping. Water losses, in this case, would be much lower than in conventional electricity generation technologies such as steam turbines from combined heat power plants.

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