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THE IMPORTANCE OF HYDROPOWER PLANTS IN THE NATIONAL POWER GRID UNDER THE CONDITIONS OF INCREASING THE CONTRIBUTION OF WIND POWER PLANTS

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Abstract: In Romania, electricity is produced in thermal, hydro, nuclear and, more and more, wind, photovoltaic or biomass power plants. Given that the total power installed in wind farms has exceeded the threshold of 3000 MW, the stability of the National Power Grid (SEN) is much more difficult to be ensured, mainly due to the intermittent nature of the wind and the fact that most wind farms are concentrated in the Dobrogea region. In order to see how important are the hydropower plants in the National Power System production-consumption balance, we chose a period of 2 years to perform an analysis of imbalances generated by wind farms.

Keywords: hydropower plant, technological reserve, secondary regulation, balancing market.

1. GENERLAL CONSIDERATIONS ON HYDROPOWER PLANTS

1.1 Evolution

Hydraulic energy has been used by humanity for thousands of years. In India and the Roman Empire water-powered mills were used to grind grain, to operate sawmills for cutting wood and stone. Water was widely used in the Middle Ages in England to extract minerals. This method evolved during the gold rush in California, USA. In the Orient, hydraulic energy was mainly used for irrigating crops. The mechanical energy required by various industries determined the location of the factories in the immediate vicinity of the watercourses. Currently, hydraulic energy is used for

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electricity production, technological development in this sector being considerable since the twentieth century.

1.2. Types of hydroelectric power plants

From the point of view of the water fall from the water inlet to the turbine level, the hydroelectric power plants can be [12]:

• with low waterfall, h <20m;
• with average waterfall 20m <h <100m;
• with high waterfall 100m <h <2000m.

Depending on the location of the plant in relation to the water source, there are run-of-the-river hydroelectric plants and plants with river deviation.

Run-of-the-river schemes are for small or medium falls, with the rise of the upstream level achieved with a dam. Among the disadvantages are the reduced accumulation possibilities, in some situations the accumulation being zero. Also, such plants have high flows, being subject to large variations in available power dictated by the tributary flow [17].

In the case of the schemes with deviation, the diversion can be done for two purposes: first, to partially take over the flow of the river (specific to low power plants); second, to increase the water fall at big HPPs. At the HPPs with raising the level upstream (moving the dam upstream from the power plant) the watercourses are diverted in the accumulation lake. The Stejaru hydroelectric power plant is such a plant.

According to the high-power turbine type, hydro aggregates can be equipped with:

- Kaplan turbines;
- Francis turbines;
- Pelton turbines.

We must notice that bulb turbines are used as well (like at Portile de Fier II, Ipotesti, Draganesti, Frunzaru, Rusanesti, Izbiceni hydropower plants). They are similar to Kaplan turbines in terms of operation but are placed horizontally.

2. TYPES OF TECHNOLOGICAL RESERVES IN THE NATIONAL POWER GRID

2.1. Primary regulation reserve

The primary regulation represents the automatic and fast control of the active power of the generating groups under the action of the local speed regulators, in order to maintain the balance between production, consumption and programmed balance (import or export) [7], [15].

The primary control reserve is represented by the power reserve which, when the frequency deviates from the setpoint set on the local controller, can be fully and automatically mobilized in 30 seconds and can remain in operation for a minimum of 15 minutes.

The primary regulation is a mandatory service for the connection to the National Power Grid (SEN) of the electricity production capacities [4], [8], [9], [13]. Also, it is not a paid service, neither at the level of insured reserves, nor at the level of activated reserves (activated power) [14], [15].

At the level of the Romania control area within ENTSO-E (European Network of Transmission System Operators), the primary control reserve is approximately 57MW [6], [11]. The offset calculation formula is:

$$s_G = \frac{\frac{\Delta f}{f}}{\frac{\Delta P_G}{P_N}} x100 \ \ [\%] \tag{1}$$

where: f is the frequency set on the regulator, P_N is the nominal active power of the group, Δf is the quasi-stationary frequency deviation, ΔP_G is the power deviation corresponding to the frequency deviation.

In Figure 1, the meaning of the notations is: P_i - initial power, P_s - stabilized power, s - degree of statism, tm_{RP} - mobilization time of the primary regulation reserve (the time in which the mobilized power falls between 1.05 and 0.95 of the calculated power to be mobilized) and ΔP_{RP} - power mobilized in primary regulation.

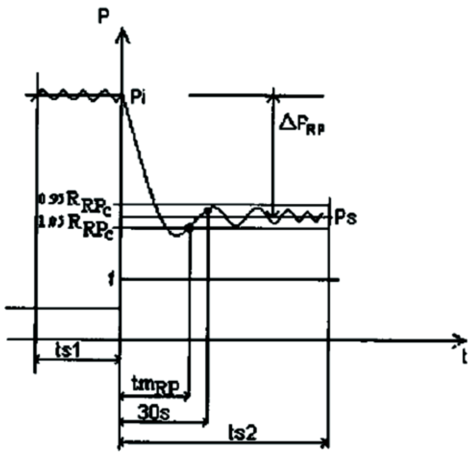

Fig. 1 Mobilization of the primary adjustment reserve

2.2. Secondary regulation reserve

The secondary regulation represents the automatic and fast control of the generating set active power using a central frequency-power regulator, in order to maintain the balance between production, consumption and programmed balance (import or export) and to restore the primary regulation reserve [1], [2].

The secondary control reserve represents the power reserve which, when the SEN frequency / balance deviates from the setpoint value, can be mobilized automatically within maximum 15 minutes.

The volume of the secondary regulation reserve recommended to be contracted by the Transport and System Operator (TSO) is calculated according to Policy 1 (ENTSO-E) [10], [11]. The calculation formula is:

$$R = \sqrt{a \cdot L_{max} + b^2} - b \quad [MW] \tag{2}$$

where R is the secondary control reserve, Lmax is the maximum consumption expected to be achieved in the control area of the central regulator, and a and b are two constants established in Policy 1 [11].

The secondary regulation power is activated by the central frequency-power regulator based on the proportional block given by the formula:

$$G_i(ACE) = \Delta P_i + K_{ri} \Delta f \tag{3}$$

where G_i is calculated depending on the active power deviation of the SEN (achieved balance-programmed balance), on the deviation from the frequency Δf and as a function of the proportionality constant K_{ri} of the regulator.

The proportionality constant K_{ri} is calculated with:

$$K_{ri} = C_i \cdot \lambda \tag{4}$$

where $C_i = 1.1$ is the contribution coefficient, and λ is the power-frequency characteristic of the grid. Thus, K_{ri} has values in the order of hundreds of [MW/Hz] (usually 500-600MW/Hz), because the frequency deviation is much smaller than the power deviation (balance).

2.3. Tertiary regulation reserve

The tertiary regulation reserve (TRR) is divided into fast tertiary reserve and slow tertiary reserve.

The fast tertiary reserve is the power reserve provided by generating sets that are qualified to ensure the loading process in maximum 15 minutes from the issuance of the dispatcher's order.

The slow tertiary reserve is the power reserve provided by generating sets that are qualified to start and load within a maximum of 7 hours from the issuance of the dispatcher's order. This type of reserve is characteristic for thermoelectric power plants, being activated when the possibility of a pronounced deficit of active power in SEN is ascertained for a longer period of time (days).

According to [11], the operation of wind farms (EC) involves ensuring additional power reserves in the SEN. Thus, the minimum value of rapid tertiary reserve required in addition to the previous values, imposed by the plant operation, is 730MW, a value to be updated from year to year, based on measured data [5].

In the case of the slow tertiary regulation reserve, these are established by the internal procedures of Transelectrica (the Romanian Transmission and System Operator) and represent 700MW, the equivalent of triggering a group from the Nuclear Power Plant of Cernavoda.

Figure 2 shows the activation of reserves in the event of an imbalance between production and consumption. Thus, in the first phase, the primary regulation reserve at the Union for the Co-ordination of Transmission of Electricity (UCTE) level is activated. The automatic activation of the secondary control reserve is performed for the restoration of the primary reserve. The manual activation of the fast and slow tertiary regulation reserve aims at restoring the secondary control reserve at the level of the control area (Romania).

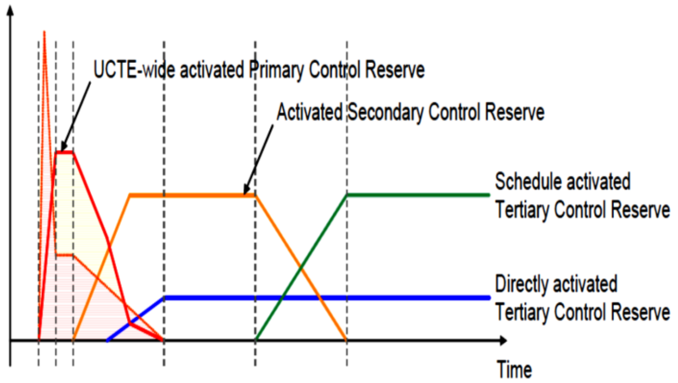

Fig. 2. The principle of mobilizing power reserves

3. THE IMPORTANCE OF HYDROPOWER PLANTS IN BALANCING THE NATIONAL POWER GRID

In order to determine how important are the hydroelectric power plants in the National Power System in ensuring the permanent production-consumption balance, we chose a period of 2 years, 2015 and 2016, to perform an analysis of imbalances generated by wind farms and the deviation between the notified consumption and the achieved one [3], [15].

Assuming that any combined imbalance of wind farms and consumption, higher than 100MWh/h, in the conditions of a high production in wind farms, will endanger the safety of SEN. However, in the situation where within SEN there is a higher quantity of fast tertiary reserve than the quantity contracted as system service, the quantity of 100MWh/h mentioned above can be exceeded with the existing spare of fast tertiary reserve.

Thus, from the Transelectrica website [16] we took data on total electricity generation and consumption, production in wind farms, in hydroelectric plants, consumption notified in SEN, production notified in wind farms, consumption forecast of DEN (National Power Dispatcher), the fast tertiary reserve activated in SEN, the total power activated on the Balancing Market and the dispatcher orders received for the hydroelectric power plants to activate the fast tertiary reserve for each hourly slot (settlement time frame) from the analyzed period [7].

The amount of information to be analyzed being of at least 17544 records on each element mentioned above, it was necessary to create a database in Microsoft Access for information processing. Thus, the total number of records required to be processed in the database was approximately 188,738 records, 65,930 being related to dispatcher orders for activating the fast tertiary reserve. The data were taken from the Transparency-Balancing and STS-Daily Reports section [16].

In the analysis we considered the defining intervals in which the module of the unbalanced production compared to the notified production in wind farms is higher than 300MWh/h.

The formulas used to highlight the magnitude of the generated imbalance are:

Imbalance_Consumption = Notified Gross Consumption_SEN-Consumption

Imbalance_Wind = WP - Notified_eolian_SEN

Necessary_BM_compensation = Imbalance_Consumption + Imbalance_Wind

where:

Notified Gross Consumption_SEN - consumption notified in SEN;

Consumption - consumption measured in SEN;

Notified_eolian_SEN – power generation in wind farms notified in SEN;

WP - electricity generated in wind farms;

Imbalance_Consumption - the imbalance of consumption, so that its positive values must be compensated by activating the balancing power to decrease (DOWN);

Imbalance_Wind - the imbalance generated by wind farms; negative values must be compensated by growth balancing power (UP);

Necessary_BM_compensation - the balancing power requirement that must be activated on the balancing market to compensate the imbalances generated by wind consumption and production wrongly estimated by producers and responsible sides for balancing (which includes electricity suppliers). If the compensation required is positive, then the necessary power to be activated by the balancing market must be of the opposite sign, to decrease the power (DOWN).

Also, in order to determine the importance of HPP in SEN balancing, we considered the defining intervals in which the energy related to the activated fast tertiary reserve, in module, was higher than 200MWh/h.

Along the National Power Grid, 4487 intervals were registered in which the module of the wind production imbalance was higher than 300MWh/h.

The energy provided by HPP in SEN by activating TTR can be found in the column Sum-of_activated energy_DO from table 1.

Table 1 ***Sample of collected data in SEN***

Interval	Production	Consumption	Wind	Hydro	Notified_wind SEN	Forcast consumption SEN	Notified Gross Consumption SEN	Imbalance consumption	Imbalance_wind	Necessary_BM compensation	Sum_of_activated energy_DO	TTR_DOWN activated_SEN	TTR_UP activated_SEN	Energy_activated SEN
13	9226.877	8090.875	2140.601	1601.608	2446.516	8100.000	8129.300	38.425	-305.915	-267.490	-220.000	414.000	0.000	-125
13	7734.745	7454.710	130.266	2442.650	439.758	7650.000	7651.297	196.587	-309.492	-112.905	-307.000	311.000	0.000	75
12	8567.279	7166.695	1870.465	1963.556	2210.714	7520.000	7552.076	385.381	-340.249	45.132	-360.500	81.167	0.000	128.833
13	8551.012	7190.455	1628.823	2026.026	2130.678	7450.000	7469.366	278.911	-501.855	-222.944	-374.667	360.500	0.000	-94.5
3	6608.911	5878.513	1365.874	1565.998	1704.898	5780.000	6647.193	768.680	-339.051	429.629	-273.667	353.667	0.000	-423.667
20	9786.061	8981.404	1223.529	1930.969	811.474	8900.000	8016.309	-965.095	412.055	-553.040	223.250	0.000	318.746	996.746
15	5861.315	4619.016	1286.763	1686.165	1629.662	4460.000	5744.306	1125.290	-342.899	782.391	-378.000	379.000	0.000	-719
11	5440.452	5221.690	1507.226	1371.785	1967.451	5230.000	6792.434	1570.744	-460.225	1110.519	-690.833	690.832	0.000	-1104.832
5	6256.941	5581.304	650.856	1194.335	994.111	5430.000	5384.330	-196.974	-343.255	-540.229	-238.167	0.000	0.000	422.133
3	6816.270	5928.284	1003.057	1225.878	1835.509	5950.000	5981.757	53.473	-832.452	-778.979	-239.083	0.000	0.000	695.416

From the collected data we noticed that in most of the intervals in which the imbalance generated by wind turbines, in module, is higher than 300MWh/h, the National Power Grid balances itself, because the balance achieved by the sold energy at insignificant prices by power producers in wind farms is a fictitious balance, the achieved (real) consumption not reaching these values. However, there are also situations in which the notified consumption is real (close to the achieved one), in these situations HPP and TRR providers intervene to balance the SEN.

4. CONCLUSIONS

During the two years we analyzed, 116 time intervals were found in which the previously mentioned conditions were observed (wind imbalance>300MWh/h, TRR activated HPP>200MWh/h). These could be critical intervals for SEN safety if HPP did not exist or did not provide TRR. Even if the significant intervals represent approximately 0.6% of the dispatching intervals related to the analyzed period, a single interval is sufficient to generate a partial or total collapse of the SEN.

However, from the data related to the balancing energy activated in the SEN, we realize that there were intervals in which the SEN imbalance was not generated only by the wind production. For an even more accurate analysis, secondary adjustment power, slow tertiary regulation power and the notifications of the other participants in the balancing market would be needed. Anyway, for most of the intervals the results are conclusive. Thus, there are intervals in which the reported production-consumption balance is fictitious, generated by low wind energy prices.

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