REPORT 1- Task 1 Reserves

Integration of Renewables in the Ukrainian Electricity System

Contents

Acronyms

Acronyms	RR (MW)
ACE	Area Control Error
ACE CL	Area Control Error - Closed Loop
ACE OL	Area Control Error - Open Loop
AFPCS	Automatic Frequency and Power Control Systems
AFR	Automatic Flow Restriction
aFRR	Automatic Frequency Restoration Reserves
BioPPs	Power plant on biogas or/and biomass
CBA	Cost Benefit Analysis
CE	Region Continental Europe (RG CE)
CENTREL	Union of electric power utilities in Central Europe (from Czech Republic, Slovakia, Poland, and Hungary)
CHPPs	Combined heat and power plant
CIS	The Commonwealth of Independent States
CTIS	collection and transfer information systems
ENTSO-E	European Network of Transmission System Operators for Electricity
FCR	Frequency Containment Reserves
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal operation
FRR	Frequency Restoration Reserves
GC	Generating company
HVDC	High Voltage Direct Current
IPS	Integrated Power System of Ukraine
LFC Area	Load Frequency Control - Area
LFC Block	Load Frequency Control - Block
mFRR	Manual Frequency Restoration Reserves
NES	New energy Strategy till 2035
NGCA	Non-government controlled area
NPC	National Power Company
NPP	Nuclear Power Plant
NWP	Numerical weather prediction
PV	Photovoltaic solar station
PVPP	Photovoltaic Power Plant
PWR	Pressurized water reactor
RES	Renewable Energy Sources
RR	Restoration Reserves
SOGL	System Operation Guideline EU 2017/1485 Guideline on electricity transmission system operation
TPP	Thermal Power Plant (coal-fired in case of Ukraine) (normally THPP is used as acronym)
TSO	Transmission System Operator
UCTE	The Union for the Co-ordination of Transmission of Electricity
UCTPE	The Union for the Coordination of Production and Transmission of Electricity
UPS	The Unified Power System of Russia
WTGS	Wind Turbine Generator System
WPP	Wind Power Plant

1 Introduction and background

According to the National Renewable Energy Action Plan for the period up to 2020, the share of renewable energy in the total final energy consumption should reach 11%, and according to the Energy Strategy of Ukraine for the period up to 2035, the share of energy from renewable sources in the primary energy supply should be 25%.

To achieve the stated goals, let alone more ambitious renewable generation targets, further integration of variable renewable energy resources should be supported by developing flexibility in current generation portfolio and by assessing the optimal dimensioning of reserves. Otherwise, the expected volume of curtailment (there will be a transition from short-term real time curtailment to planned long-term ones) might increase up to sizeable amounts of the total electricity produced from renewable energy sources (RES), which will be unused, but must be paid by consumers under current market rules. Thus, a number of changes should be made both in the market design and in the generation fleet.

Currently, the Transmission System Code does not consider the effect of variable renewables on the need of capacity reserves of Ukraine's power system. This fact leads to high risks for further development of variable renewables in Ukraine, due to the high uncertainties related to the existing capacity reserve assessments, and insufficient knowledge of reserve needs when setting up corresponding requirements in the conditions for high variable renewables penetration in the country. In addition, the change of operational practice to fit the challenges in the dynamics in the electricity system (including a large amount of RES or having a large fluctuation from demand facilities) plays a crucial role.

Therefore, determining adequately the reserve needs under high shares of variable renewables in the power system is one of the key challenges of Ukraine's Integrated Power System (IPS). Addressing this issue, as well as rethinking the overall concept of energy system management with a significant share of RES, will facilitate the integration of more renewable energy by providing more accurate reserve assessments and additional flexibility resources of current generation and demand portfolio..

2 Definitions of reserves

2.1 General

From 2023 Ukraine is expected to join the ENTSO-E (assuming that the system will be connected to the Central European grid system (RG CE) and disconnected from the Unified Power System of Russia (UPS)), provision should be made for the use of such reserves and to the extent that they will comply with SOGL.

Currently, Ukraine uses (only in interconnected mode) a similar approach to that set out in SOGL.

Thus, both in SOGL (i.e. RG CE) and in the current Ukrainian Network code, 3 categories of reserves are distinguished [1]:

1) Frequency containment reserve (FCR) (definitions and requirements for such are given in SOGL articles 153-156); 'FCR' means the active power reserves available to contain system frequency after the occurrence of an imbalance;
2) Frequency replacement reserve (FRR) (definitions and requirements for such are given in SOGL articles 157-159); 'FRR' means the active power reserves available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore power balance to the scheduled value;
3) Replacement reserves (RR) (definitions and requirements for such are given in SOGL articles 160-162); 'RR' means the active power reserves available to restore or support the required level of FRR to be prepared for additional system imbalances, including generation reserves.

In addition, the Ukrainian Network code provides for the division of the first category of reserves into two parts, which can be used only in isolated mode:

1) Frequency containment reserve for normal state (FCR-N);
2) Frequency containment reserve in disturbed state (FCR-D).

At the same time, it should be emphasized that the presence of all types of reserves in the IPS of Ukraine (including FCR-N and FCR-D) is the key to successful testing of an UA island mode of operation, the results of which (such a criterion is not the only one) will draw conclusions about the possibility of integration of the IPS of Ukraine into the RG CE grid system.

2.2 FCR - Frequency Containment Reserves

Currently, the requirements of the Ukrainian Network code are as follows [2]:

According to the current code of the Transmission System, the accepted values of initial liabilities from the primary reserve for the IPS of Ukraine, depending on the mode of its operation should be:

- In the island mode ± 1000MW. In this mode, this value can be the total amount of FCR and FRR;
- in the interconnected mode with ENTSO-E and separately from the power system of the CIS and Baltic countries, the values of initial commitments from the primary

reserve for IPS of Ukraine depending on the mode of its work and determined by the TSO;

- in the interconnected mode with the power system of the CIS and Baltic countries and separately from ENTSO-E the accepted values of initial commitments from the primary reserve for IPS of Ukraine depending on the mode operation of its work and determined by the TSO.

Currently, the requirements of the SOGL are as follows (see Article 153):

FCR dimensioning

1. All TSOs of each synchronous area shall determine, at least annually, the reserve capacity for FCR required for the synchronous area and the initial FCR obligation of each TSO in accordance with paragraph 2.
2. All TSOs of each synchronous area shall specify dimensioning rules in the synchronous area operational agreement in accordance with the following criteria:
   (a) the reserve capacity for FCR required for the synchronous area shall cover at least the reference incident and, for the CE and Nordic synchronous areas, the results of the probabilistic dimensioning approach for FCR carried out pursuant to point (c);
   (b) the size of the reference incident shall be determined in accordance with the following conditions:
      (i) for the CE synchronous area, the reference incident shall be 3 000 MW in positive direction and 3 000 MW in negative direction;
      (ii) for the GB, IE/NI, and Nordic synchronous areas, the reference incident shall be the largest imbalance that may result from an instantaneous change of active power such as that of a single power generating module, single demand facility, or single HVDC interconnector or from a tripping of an AC line, or it shall be the maximum instantaneous loss of active power consumption due to the tripping of one or two connection points. The reference incident shall be determined separately for positive and negative direction;
   (c) for the CE and Nordic synchronous areas, all TSOs of the synchronous area shall have the right to define a probabilistic dimensioning approach for FCR taking into account the pattern of load, generation and inertia, including synthetic inertia as well as the available means to deploy minimum inertia in real-time in accordance with the methodology referred to in Article 39, with the aim of reducing the probability of insufficient FCR to below or equal to once in 20 years; and
   (d) the shares of the reserve capacity on FCR required for each TSO as initial FCR obligation shall be based on the sum of the net generation and consumption of its control area divided by the sum of net generation and consumption of the synchronous area over a period of 1 year.

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2.3 FRR - Frequency Restoration Reserves

Currently, the requirements of the Ukrainian Network code are as follows:

Requirements for secondary frequency control and frequency recovery reserves (secondary control reserve):

1) secondary adjustment is performed for:
   - maintaining the frequency within acceptable limits;
   - maintaining the power balance of the IPS of Ukraine / load unit / synchronous area by adjusting the set with frequency correction of the total external flow of the IPS of Ukraine / load-frequency control block / synchronous area;
   - support of balance of power flows on internal and external communications and sections in admissible ranges;
   - ensuring the restoration of primary regulation reserves;
2) in the IPS of Ukraine / load-frequency control block / synchronous area should be carried out continuously:
   - secondary frequency regulation in the IPS of Ukraine in the mode of separate operation;
   - exchange of power control with adjacent c load-frequency control blocks / synchronous area power systems with frequency correction in interconnected operation mode;
   - limiting power flows through internal and external connections;
3) the procedure for organizing secondary frequency regulation in the synchronous region should be jointly established by the TSOs of countries whose power systems operate synchronously;
4) as a result of the operation of the secondary control system, the total external flow of the IPS of Ukraine / control unit / synchronous region must be maintained at a given level at nominal frequency. At the same time, internal disturbances of the power balance of the IPS of Ukraine / control unit / synchronous region power systems must be eliminated by the relevant TSO for a time not exceeding 15 minutes;
5) the secondary regulation system of the IPS of Ukraine / control unit / synchronous area should not respond to power imbalances that have occurred in neighboring control units / power systems of the synchronous area. At the same time, the secondary regulation system of the IPS of Ukraine / control unit / synchronous area should not interfere with the primary regulation of the IPS of Ukraine / control unit / synchronous area. As the secondary regulation of the IPS of Ukraine / control unit / synchronous region, by influencing its generating units, compensates for the power imbalance that has arisen in it, the frequency maintenance reserves must be restored to the initial values;
6) in the IPS of Ukraine, the TSO must determine power lines and internal and interstate crossings, the overloading of which may lead to a violation of the stability of synchronous operation. Automatic flow restriction (AFR) or operational flow restriction must be organized on these transmission lines and in cross-sections. As a part of the Automatic frequency and power control systems (AFPCS) high-speed AFR on these lines and sections made in the form of integrated regulators with an adjustable insensitivity zone should be provided;

7) overloads should be detected and eliminated by the AFR, and in its absence / inefficiency - promptly in a minimum time, but not more than 20 minutes in static modes. For the intersections referred to in sub-clause 6 of this sub-clause, the TSO shall identify secondary control power plants with a frequency recovery reserve sufficient to prevent (eliminate) congestion;

8) secondary regulation of a given total external flow with frequency correction should be performed according to the criterion of network characteristics, and the adjustable parameter (to be reduced to zero) is the error of regulation of the area G or area control error (ACE). The adjustment of area control error G is calculated by the formula

$G = \Delta P + Кч\Delta f$,

the amount of required FRR in the area of regulation of the IPS of Ukraine / the area of regulation "the Burshtynska TPP island" / LFC block / synchronous area should be sufficient to compensate:

- irregular fluctuations of power imbalance;
- dynamic errors of power balance adjustment during the hours of the variable part of the load schedule;
- the most probable accidental loss of generation or consumption (reliability criterion N-1) in the area of regulation of the IPS of Ukraine / the area of regulation "the Burshtynska TPP island" / LFC block / synchronous area;

9) FRR may consist of reserves that are activated in automatic (aFRR) and manual (mFRR) modes. The value of the minimum aFRR is determined by the formula

$$R = \pm\sqrt{a \cdot P_{макс} + b^2} - b \;,$$

where $P_{макс}$ - maximum load in the IPS of Ukraine / LFC block / synchronous area, MW;

a = 10MW i b = 150 MW - empirical coefficients.

If the estimated power imbalance in the IPS of Ukraine / control unit / synchronous region associated with the loss of generation is greater than the value of R, the value of the reserve for loading should be taken equal to the value of this calculated imbalance.

Next, R is compared with:

- the value of the installed capacity of the most powerful power unit in the IPS of Ukraine / LFC block / synchronous area;
- the value of the capacity of the most powerful node of electricity consumption, the loss of which is possible in case of disconnection of one element of the network.

The final value of the FRR is defined as the largest modulo values of these two components, and the range of secondary control may be asymmetric.

For the regulation area "the Burshtynska TPP island":

The principle of determining the FRR meets the requirements of the Catalog of measures for the inclusion in interconnected mode of the south-western part of the Ukrainian power system, the area of regulation of the "the Burshtynska TPP island" with the Union of electric power utilities in Central Europe (CENTREL) and the Union for the

Coordination of Production and Transmission of Electricity (UCPTE) and is equal to the capacity of the most powerful operating unit.

aFRR should be ± 10% of the coverage of the regulation area "the Burshtynska TPP island".

The value of mFRR for the IPS of Ukraine / Burshtynska TPP island regulation area is calculated as the difference between the estimated value of FRR and the calculated value of aFRR;

10) the estimated value of FRR is determined based on the need to compensate for the most probable accidental loss of generation or consumption and should be:

- for the field of regulation of the IPS of Ukraine:
- for upward - 1000 MW;
- for downward - 500 MW;
- for the area of regulation "the Burshtynska TPP island:
- for upward - the amount of reserve is determined in accordance with the algorithm defined in subparagraph 15 of this subparagraph;
- for downward - 100 MW.

In the IPS of Ukraine, the FRR should be located in separate periods at least on 30 generating units;

11) in the field of regulation of IPS of Ukraine / in the field of regulation "the Burshtynska TPP island" the choice of units of FRR supply, definition for them of ranges of secondary regulation and FRR for loading and unloading is carried out by TSO according to Market rules.

Maneuverable generating units should be involved in automatic secondary control, as well as consumers with adjustable load that meet the requirements of automatic secondary control, capable of changing the power within the specified secondary reserve under the action of the central regulator. Generating units involved in secondary regulation must meet the requirements of regulatory and technical documents on the characteristics of maneuverability (Standards of minimum allowable loads of power units, Standards of maximum allowable speeds of load change during operation of power units 160-800 MW in the control range). When selecting power plants for secondary regulation and placing secondary reserves on them, their maneuverability and control capabilities should be taken into account, and secondary reserves should be placed on power plants so that they can be used to unload overloaded connections and cross-sections;

12) power plants and power units involved in secondary regulation have:

- to ensure compliance with the technical requirements for secondary regulation established by the TSO in accordance with the requirements of this Code;
- to install and ensure the operation of collection and transfer information systems (CTIS) equipment and equipment that registers the actual involvement of the power plant and each power unit in the regulation, receives control signals from the central regulator (AFPCS), exchanges information with this central regulator (AFPCS) and meets the requirements established by TSO requirements of this Code;

13) the minimum technical requirements for FRR should be as follows:

- activation of the unit (group) of FRR provision should take place in accordance with the set point, received from the TSO with a delay not exceeding 30 seconds;
- the time of commissioning (full activation) of the FRR is not more than 15 minutes;
- stable delivery of FRR from the moment of commissioning (before commissioning of necessary RR), ie not less than 60 minutes;
- the accuracy of measuring the active capacity of the unit (group) of FRR supply and the accuracy of maintaining the set capacity must not be worse than ± 1.0% of the nominal capacity of the unit (group) of FRR supply;
- parameter measurements and information transmission must be performed with a cycle of no more than 1 second;
- the FRR supply unit (group) must meet the requirements for the rate of change of load;

14) every FRR supplier must:

- confirm that its FRR supply units (groups) meet the minimum technical requirements for FRR and the requirements for FRR readiness;
- notify the TSO of a reduction in actual readiness or an emergency shutdown of its unit (group, part of a group) of FRR supply as soon as possible.

While SOGL states the following (see SOGL Article 157)

FRR dimensioning - imbalances

All TSOs of a LFC Block shall set out FRR dimensioning rules in the LFC Block operational agreement.

The FRR dimensioning rules shall include at least the following:

- all TSOs of a LFC block in the CE and Nordic synchronous areas shall determine the required reserve capacity of FRR of the LFC block based on consecutive historical records comprising at least the historical LFC block imbalance values. The sampling of those historical records shall cover at least the time to restore frequency. The time period considered for those records shall be representative and include at least one full year period ending not earlier than 6 months before the calculation date;
- all TSOs of a LFC block in the CE and Nordic synchronous areas shall determine the reserve capacity on FRR of the LFC block sufficient to respect the current FRCE target parameters in Article 128 for the time period referred to in point (a) based at least on a probabilistic methodology. In using that probabilistic methodology, the TSOs shall take into account the restrictions defined in the agreements for the sharing or exchange of reserves due to possible violations of operational security and the FRR availability requirements. All TSOs of a LFC block shall take into account any expected significant changes to the distribution of LFC block imbalances or take into account other relevant influencing factors relative to the time period considered;
- all TSOs of a LFC block shall determine the ratio of automatic FRR, manual FRR, the automatic FRR full activation time and manual FRR full activation time in order to

comply with the requirement of paragraph (b). For that purpose, the automatic FRR full activation time of a LFC block and the manual FRR full activation time of the LFC block shall not be more than the time to restore frequency;

FRR dimensioning – reference incident

- the TSOs of a LFC block shall determine the size of the reference incident which shall be the largest imbalance that may result from an instantaneous change of active power of a single power generating module, single demand facility, or single HVDC interconnector or from a tripping of an AC line within the LFC block;
- all TSOs of a LFC block shall determine the positive reserve capacity on FRR, which shall not be less than the positive dimensioning incident of the LFC block;
- all TSOs of a LFC block shall determine the negative reserve capacity on FRR, which shall not be less than the negative dimensioning incident of the LFC block;
- all TSOs of a LFC block shall ensure that the positive reserve capacity on FRR or a combination of reserve capacity on FRR and RR is sufficient to cover the positive LFC block imbalances for at least 99 % of the time, based on the historical records referred to in point (a);
- all TSOs of a LFC block shall ensure that the negative reserve capacity on FRR or a combination of reserve capacity on FRR and RR is sufficient to cover the negative LFC block imbalances for at least 99 % of the time, based on the historical record referred to in point (a).

2.4 Other reserves

Currently, the requirements of the Ukrainian Network code for tertiary regulation reserves are as follows:

Requirements for tertiary frequency control and substitution reserves:

1) to maintain the set values of FCR and FRR and restore these reserves in case of their use in the process of frequency regulation in the IPS of Ukraine / LFC block / synchronous area, tertiary regulation should be carried out and a replacement reserve (for unloading and loading) should be created. Tertiary control sets the power of generating units, relative to which the ranges of primary and secondary control;
2) the planned capacity of the generating unit or consumption unit involved in tertiary regulation is calculated so as to ensure the possibility of using the specified ranges of FRR and FCR;
3) TSO must apply tertiary regulation before the FRR is exhausted. Tertiary regulation should be used in case of reduction of FRR for loading or unloading to 20% of the required volume. In this case, the TSO must expect the team to activate the replacement reserve so that no later than 30 minutes from its issuance to fully restore the FRR;
4) to provide a tertiary reserve to restore the regulatory capacity of primary and secondary regulation should be used:
    - start-up of reserve generating units;

- stop of operating generating units;
- start in the generator or pump mode of PSP units;
- upward / downward the generating units;
- switching off / on consumption units;
- changing schedules for exchanging power flows with other power systems;

5) the substitution reserve can also be used to provide emergency mutual assistance at the request of adjacent TSO control units / synchronous area, after registration through the TSO manager of the appropriate correction of the specified operating modes (load schedules of generating units, specified external flow balance, etc.) IPS of Ukraine;
6) the substitution reserve must be sufficient to ensure the effective operation of the primary and secondary control in a given amount and with the required quality of control, as well as to compensate for the error of planning the power balance and loss of generation;
7) for the IPS of Ukraine, the estimated replacement reserve based on statistical data on actual imbalances for the IPS of Ukraine regulation area for the previous 10 years should be:
    - for upward - not less than 1000 MW;
    - for downward - not less than 500 MW.

3 Methodologies to assess the required amounts of reserves in 2030 in Ukraine

3.1 General

Based on the results of the analysis of the previous sections, it was found that there is a difference in the methodologies for determining the required amount of reserves. So far, only in the context of Ukrainian-Danish cooperation, there have been at least 4 different methodologies: 2 in Ukraine (different for the Burshtynska TPP island and the main part of the IPS of Ukraine) and 2 in ENTSO-E (different for Continental Europe and the Nordic countries).

In many European power systems sometimes use a graphical method to determine the minimum amount of aFRR as in Figure 1 (such requirements correspond to those that currently take place in the main part of the IPS of Ukraine).

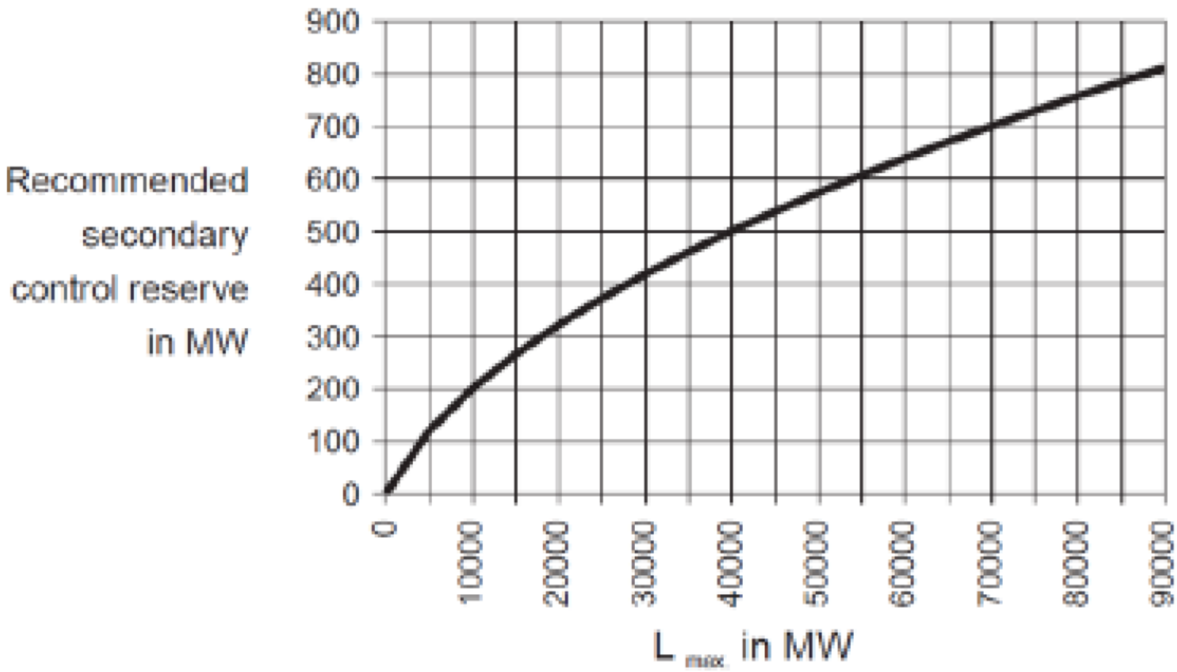

Figure 1. Recommended minimum amount of aFRR (according to UCTE methodologies)

However, due to the fact that this approach to determining the required volumes does not take into account a lot of other (no less important), factors other than peak load, so this approach is not widely used.

Obviously, in the context of the future integration of the IPS of Ukraine into the RG CE the EU must be implemented, and therefore at least the approaches to determining support and frequency recovery reserves (FCR and FRR) should change. In this manner the responsibility for keeping the balance still is on the table of Ukrainian TSO and the responsibility of the reserves are shared within the LFC Block.

Currently in Ukraine FCR consists (respectively, determined by the transmission system operator) of FCR-N (for normal operating conditions of the power system) and FCR-D (for accident or other disturbances), when in the case of RG CE such division none (according to the ENTSO-E methodologies, the maximum perturbation in the synchronous zone up to 3000 MW is assumed in the CE synchronous zone). Similarly, using other approaches, aFRR and mFRR are determined (or the total FRR and the ratio of its components).
Data in the Table 1 shows the minimum reserves (by type) in Ukraine.
As the Ukrainian energy system currently consists of two asynchronous zones (IPS of Ukraine and the Burshtynska TPP island), the table shows the requirements only for IPS of Ukraine, as from 2023 it is envisaged to combine these two zones.

Table 1. Minimum reserves by type in the Ukrainian energy system, MW

Zone	FCR (MW)	FRR (MW)	RR (MW)
Main part of the IPS of Ukraine	±119	+1000 -421	+1000 -500
Burshtynska TPP island	±8	+210 -100	+210 -100

It should be noted that the minimum FCR volumes in each of the zones may vary by several MW, as they are periodically reviewed (in accordance with current requirements and the PCB). Also, these methodologies do not take into account the impact of increasing the share of RES capacity in the energy system on the minimum amount of reserves in order to ensure balance reliability.
As noted, data were used to determine the minimum reserves (first of all, the calculated values of ACEol and ACEcl, CONTROL PROGRAM, intended deviations, aFRR / mFRR / RR schedule, based on the results of which analysis and application of the probabilistic approach determined the minimum reserves. As shown in the methodology in the Figure 2 and Figure 3 below.

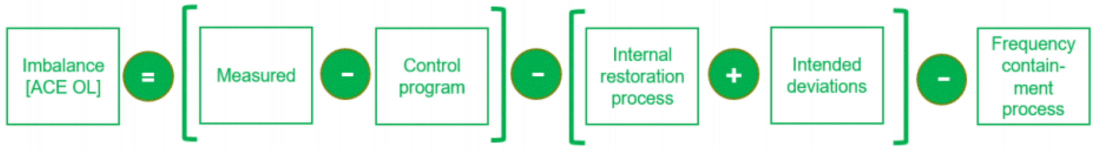

Figure 2. ACE OL calculating principles

Figure 3. ACE CL calculating principles

It should be noted that according to the ENTSO-E methodology, the relevant data for a period of at least one year should be used, however, due to the fact that the ancillary services market in Ukraine (after changing the electricity market model) started operating less than a year ago, may after recalculation in the future may be clarified.
To determine certain indicators, the data of the SCADA system and metrology given in «IMBALANCE PROJECT. Final report» and «Nordic report, Future System Inertia External version and Solving the Nordic inertia challenge with FFR» provided by Energinet team and in "Methodology for the dimensioning of the aFRR needs – Elia" [3].

3.2 Proactive and reactive balancing approaches

In the framework of consultations with colleagues from Energinet, 2 fundamentally different concepts for balancing in the energy system were presented. The advantages and disadvantages of each of them are also given, as well as the presence of the third concept, which is the result of the synthesis of the two previous ones.
Based on the results of the analysis of the IPS of Ukraine, it was established that currently in Ukraine in the vast majority of cases the concept of conditional reactive approach to balancing in the energy system is used (except for a number of preventive measures).
Based on the main disadvantage (the need for significant volumes of automatic reserves and, accordingly, the high cost) of a purely reactive approach to balancing, it is advisable in the deficit of reserves to make the transition to a purely proactive (or hybrid approach). When changing the concept, the quality of forecasts of production of SPP, WPP, load and other undispatched capacities play an important role.

3.3 Requirements for forecasting wind and solar

It is also worth noting that the current Network Code has the following requirements for forecasting wind and solar:

1) For WPPs and PVPPs, annual, monthly, weekly and daily forecasts are provided as the total capacity of wind power plants or solar panels with inverters;
2) Network users must ensure accurate forecasting of electricity consumption / production and timely provision of TSO GSP data;
3) TSO has the right to reject the submitted forecast of electricity production of an individual party, if the provided forecast is not realistic, notifying the relevant User.

Obviously, the quality of PVPP and WPP production forecasts has a significant impact on the need for appropriate reserves (first of all on aFRR). However, their quality has a much smaller impact on the need for other capacity in the balancing market (so, even in the conditions of zero error of forecasts it is necessary to reach balance in power system. At present, forecast errors in Ukraine reach 10% (while in developed EU countries such figures vary within 3-5%), obviously efforts should be made to improve forecasts (for example, by expanding the set of tools and implementing modern forecasting models).

International consultants provided after analyzing the forecasting system in Ukraine the following recommendations how to improve the quality of wind and solar forecasting. The main and the most effective ones are the following:

1) Work together with forecasts providers (like Siemens and others);
2) Use of new and additional Numerical weather predictions (NWP) providers for the in-house systems;
3) Use of probabilistic approach for forecasting.

3.4 Collection of data for reserve assessment

Based on the results of the last Ukrainian Mid-term adequacy report (in early 2020) we suppose that annual demand in Ukraine will be within the range presented in Table 2.

Table 2. Minimum and Maximum Annual Electricity Demand Assessment, bn kWh

Indicator	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Electricity consumption (gross) (minimum assessment)	151	152	153	154	154.5	155	156	157	157.5	158.5
Electricity consumption (gross) (maximum assessment)	155	156	158	160	161.5	162.5	164	166	167.5	169

So, the base-line scenario envisages the following transformation of the generating facilities structure in the period of 2021-2030 (see Table 3).

Table 3. Expected installed capacities under Base-line Scenario

Indicator	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
WPPs installed capacities by year end, GW	3.2	3.5	3.8	4.1	4.5	4.9	5.3	5.7	6.1	6.5
Annual average WPPs capacities, GW	2.75	3.35	3.65	3.95	4.3	4.7	5.1	5.5	5.9	6.3
WPPs capacity factor, relative units	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
SPPs installed capacities by year end, GW	6.7	7.025	7.35	7.675	8.1	8.525	8.95	9.375	9.8	10.225
Annual average SPPs capacities, GW	6.163	6.863	7.188	7.513	7.888	8.313	8.738	9.163	9.588	10.013
SPPs capacity factor, relative units	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147
coal-fired TPPs, GW	15.4	15.4	13.8	11.2	8.2	6.5	5.2	3	2.4	1.9
oil/gas TPPs, GW	3	2.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
TPPs, GW	6.1	5.8	5.5	5.2	4.9	4.6	4.3	4	3.7	3.4
HPPs, GW	4.82	4.84	4.86	4.88	4.9	4.9	4.9	4.9	4.9	4.9
PSHPPs, GW	1.474	1.798	1.949	1.949	1.949	1.949	1.949	1.949	1.949	1.949
NPPs, GW	13.835	13.835	13.835	13.835	13.835	13.835	13.835	13.835	13.835	13.835

In dimensioning reserves process a lot of other internal data of NPC Ukrenergo (from one-minute intervals to hourly and annual) were used.

3.5 Assessment of required reserves - focus 2030

Among the key assumptions (see para. 3.4) should be noted that the modeling takes into account the inaccuracy of forecasts that currently occurs in the IPS of Ukraine (± 10%), as well as the application of a conditionally reactive approach to balancing (currently used in Ukraine, see para. 3.3).

The simulation assumes (see Table 4) the use of a scenario approach, which simulates the operation of the IPS of Ukraine (in parallel with RG CE) for the following 4 scenarios (it is assumed that all other, above assumptions will be unchanged for all scenarios).

Table 4. Description of variable simulation scenarios

Scenario	Installed capacity (GW)	2025	2030
s1	SPPs	8,1	10,2
	WPPs	4,5	6,5
s2	SPPs	9,1	11,2
	WPPs	5,5	7,5
s3	SPPs	10,1	12,2
	WPPs	6,5	8,5
s4	SPPs	11,1	13,2
	WPPs	7,5	9,5

The simulation results for the scenarios are given in Table 5 below.

Table 5. Results of modeling the functioning of the IPS of Ukraine according to the scenarios in 2025 and 2030

Scenario	Minimum required reserves by types (MW)				
	FCR	aFRR	mFRR*	FRR	RR
S1.25	119	384	616	1000	1000
S2.25	119	396	616	1000	1000
S3.25	119	444	556	1000	1000
S4.25	119	378	622	1000	1000
S1.30	119	409	591	1000	1000
S2.30	119	430	570	1000	1000
S3.30	119	469	531	1000	1000
S4.30	119	388	612	1000	1000

* mFRR is a difference between FRR and aFRR

It should be noted that with the corresponding increases in RES capacity, the energy system of Ukraine needs additional generating capacity (including flexible balancing facilities).

Increasing balancing capacity with increasing share of RES is not something fundamentally new, as it has sharpened the attention of Ukrainian TSO, ENTSO-E, the Energy Secretariat, and other European TSOs [4], [5].

As classical reserves are not the only balancing tool in ENTSO-E and are not provided free of charge, ENTSO-E has developed a methodology for valuating these resources based on the results of a cost-benefit analysis (CBA [6]).

The most common and often interconnected means / tools to improve balancing opportunities in the energy system (based on European cost-benefit analysis results) today (in particular, in the EU) are:

1. Strengthening financial responsibility for imbalances for RES producers (with reference to the interest of electricity market participants in forming balancing groups, maintaining balances, improving forecasts, etc.).
2. Priority of balancing market development (avoidance of regulatory distortions in this market segment, expansion of economic freedom of participants in this market segment to form a price offer, geographical expansion of this market segment, creation of common single balancing market with neighboring countries, etc.).
3. Adaptation of market conditions in accordance with the technical needs of the energy system:
   a) Providing an opportunity to sell goods and services (including electricity) in the country at negative prices;
   b) Stimulating the development of flexible technologies for the production / consumption of electricity;
   c) Narrowing of trade windows in the intraday market (from 1 hour to 30, 20 or 15 minutes);
4. Encouraging the participation of producers in the provision of ancillary services and active participation in balancing the energy system.
5. Formation of correct price-caps in the market of ancillary services for different types of such services (creation of price differentiation for different types of reserves).

At present, in accordance with the current legislation, TSO cannot directly affect the implementation (or to improve the level of its efficiency) of the listed instruments. Therefore, in the conditions of reducing the flexibility (initially insufficient), the needs of which only increase over time. In order to keep balance in the energy system Ukrainian TSO will be forced to increase the minimum reserves. However, such a decision is not economically justified (not only for the TSO, but also for the welfare of all participants in the electricity market).

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