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Ukraine & Moldova Power Systems Interconnection – Additional Studies

Studies for a synchronous interconnection of the grids of Continental Europe and Ukraine/Moldova using the present network

Executive Summary

Introduction and objectives

Moldelectrica and Ukrenergo expressed their interest in the implementation of joint synchronous integration of the power systems of Ukraine and Moldova into ENTSO-E and concluded a respective agreement on cooperation on 12 September 2006.

A consortium of ENTSO-E members was formed in 2014 to elaborate the “Feasibility Study on the Synchronous Interconnection of the Ukrainian and Moldovan Power Systems to ENTSO-E Continental Europe Power System” (“Feasibility Study”). The Feasibility Study was finalized in January 2016 and was made in the framework of The Joint Operational Program Romania-Ukraine-Republic of Moldova 2007-2013 which was financed by the European Union through the European Neighborhood and Partnership Instrument and co-financed by the participating countries in the program. The Feasibility Study was done using forecasted 2020 network models.

Ukrenergo and Moldelectrica signed the agreements on the conditions for the future interconnection of the power systems of Ukraine and Moldova with the Power System of Continental Europe with ENTSO-E system operators on 28 June 2017 and 29 June 2017 respectively. These agreements contain Catalogues of Measures to be implemented in Ukraine and Republic of Moldova.

According to these agreements “Additional Studies on Synchronous Interconnection of the Ukrainian and Moldovan Power Systems to the ENTSO-E Continental European Power System” (hereinafter referred to as “**Additional Studies**”) must be performed:

- Steady state calculations for a synchronous interconnection of the grids of Continental Europe and Ukraine/Moldova using the present network (hereinafter referred to as “**Steady State Calculations**”).
- Dynamic calculations for a synchronous interconnection of the grids of Continental Europe and Ukraine/Moldova using the present network and the detailed dynamic models of the Ukrainian and Moldovan power systems (hereinafter referred to as “**Dynamic Calculations**”).

On 16 October 2017 the letters from ENTSO-E Secretary General Laurent Schmitt were sent to the heads of Moldelectrica and Ukrenergo, stating that “Only this consortium [i.e. a consortium of Transmission System Operators of the Continental European synchronous area] is authorized to collect the full scope of information and will be perceived by us as the only structure that can and is able to perform the complete assessment of the power system”.

On 12 April 2018, the “Memorandum between the Ministry of Energy and Coal Industry of Ukraine and the Ministry of Economy and Infrastructure of the Republic of Moldova on joint activities aimed at ensuring European integration processes to achieve the synchronous operation of the power systems of Ukraine and the Republic of Moldova with ENTSO-E” was signed.

In this context, a Consortium of TSOs who are members of ENTSO-E was established to carry out the Additional Studies. The Consortium leader is Transelectrica (Romania), as a party supporting the synchronous connection of the power systems of Ukraine and Moldova with Continental Europe ENTSO-E. The other TSOs consortium members are EMS (Serbia), MAVIR (Hungary), PSE (Poland), SEPS (Slovakia) and 50Hertz (Germany). EKC – Electricity Coordinating Center Ltd was subcontracted by EMS and Institute of Power Engineering Research Institute – Gdansk Division was subcontracted by PSE.

Ukrenergo and Moldelectrica signed separate service agreements with the Consortium for the execution of the Additional Studies.

The overall objective of the Additional Studies is to support the synchronous connection of the Ukrainian and Moldovan Power Systems to ENTSO-E Continental Europe Power System by analyzing possible technical obstacles and identifying the measures to overcome them.

The activities for these additional studies are organized in two working groups:

- WG1 – performance of the Steady State Calculations
- WG2 – performance of the Dynamic Calculations

The geographical area, which is a subject of investigation, covers the network of Ukraine, Moldova (UA/MD) and ENTSO-E Continental Europe synchronous zone, and it is especially focused to the networks from the countries to which the UA/MD network will be connected.

This document provides main results and conclusions from activities performed within WG1 (Part 1. Steady State Study) and WG2 (Part 2. Dynamic Study).

The steady state calculations included data collection and validation, analysis of synchronous connection of UA/MD to the ENTSO-E in case of zero exchange, analysis of loop and transit flows, determination of the observability area to be modeled in EMS/SCADA system of Ukrenergo, Moldelectrica and their neighboring TSOs, analysis of exchange scenarios and calculation of maximum transfer capacities, calculation of three-phase short-circuits.

The dynamic calculations included data collection and validation, dynamic stability analysis, frequency stability calculations and development of countermeasures for the identified risks.

Part 1. Steady state study

Data collection

Final goal of data collection process was to create merged models of present network for steady state analyses for Winter Peak 2020 and for Summer off Peak 2020.

Region that was modeled is shown in Figure 1, from which can also be seen which sources have been used in process of model collection.

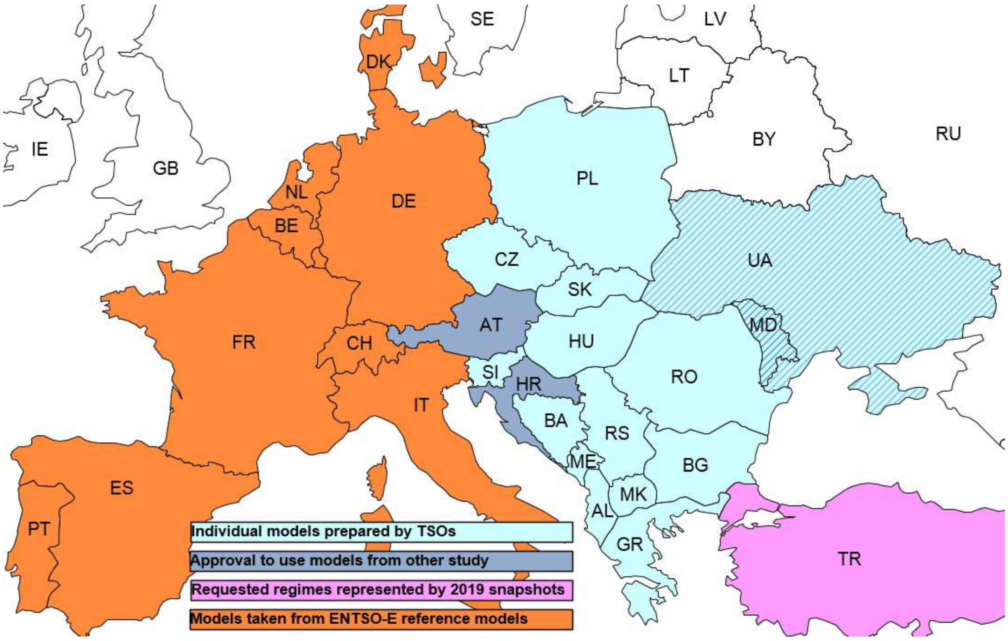

Figure 1: Area modeled for purpose of this study

Analysis of synchronous connection of UA/MD to the ENTSO-E in case of zero exchange

After the synchronous interconnection it resulted that in the most countries the voltage profile practically remained the same. Connection of UA/MD to the ENTSO-E CE has slight influence to voltage profile.

Connection of UA/MD to the ENTSO-E CE has slight influence to active power losses:

- In Winter Peak regime total losses are decreased by around 10 MW, which is relative decrease of around 0,12%
- In Summer Off-Peak regime total losses are increased by around 5 MW, which relative increase of around 0,11%

From contingency analyses resulted that connection of UA/MD to the ENTSO-E CE does not have any influence to security of ENTSO-E CE part of the grid.

Analysis of loop and transit flows

A loop flows represent the difference between the scheduled and actual power flow, assuming zero inadvertent interchange, on a given transmission path in a meshed grid. In this case, the scheduled flows are the flows before interconnection. After interconnection, zero exchanges between UA/MD (IPS part) and ENTSO-E CE is assumed.

Connection of UA/MD to the ENTSO-E CE causes the following loop flows:

- In Winter Peak regime, total loop flow of around 220 MW
- In Summer Off-Peak regime, total loop flow of around 61 MW

In the models with two synchronous zones as well as in the merged models it can be seen that, although Burshtyn Island exports power to the ENTSO-E CE region, there is power flow from Slovakia to Ukraine. This means that there is transit flow from Slovakia, through Burshtyn Island, to Hungary and Romania.

The detected loop flows and transit flows are not so significant, so they should not be considered as reason for large investments in the grid.

Determination of the observability area

Determination of observability area to be modeled in EMS SCADA system of Ukrenergo, Moldelectrica and their neighboring systems was provided in the Study. In addition, within this task, external contingency list has also been determined for each of these TSOs.

The respective selected external contingencies indicate the elements in the observability area which should be modeled in the EMS SCADA system (power stations, lines, transformers, etc.). Based on these selected external contingencies, the external contingency list for security analyses will be formed.

Analysis of exchange scenarios

Analysis of exchange scenarios have been made in order to estimate maximum power transfers after the interconnection of UA/MD and ENTSO-E CE, in the following directions:

- UA+MD → SEE + IT (via HVDC)
- UA+MD → SI + AT + IT (without HVDC)
- UA+MD → DE
- DE → UA+MD
- UA+MD → PL + SK + HU + RO + CZ
- PL + SK + HU + RO + CZ → UA+MD
- UA+MD → SK + HU + RO
- SK + HU + RO → UA+MD
- UA+MD → PL + SK
- UA+MD → SK + HU
- UA+MD → HU + RO

In case of exchanges with neighboring systems, maximum secure exchange is about 1250 MW from UA/MD to CE and about 750MW from CE to UA/MD for winter peak, and about 1700 MW from UA/MD to CE and about 800MW from CE to UA/MD for summer off-peak.

Short-circuit calculation

In order to estimate general influence of the connection of UA/MD to ENTSO-E Continental Europe grid to size of equipment, short-circuit calculation has been performed. The calculation has been made for case when these two systems are not connected (prior to connection) as well as for case of synchronous connection of these two systems. Thus, influence of this connection can be estimated.

According to the results from three phases short-circuit calculations the values of short-circuit currents are below typical breaking capability of 31,5 kA in all cases.

Conclusions

From steady-state analyses point of view, the synchronous connection of Ukraine and Moldova to the continental part of ENTSO-E is feasible and without any request for reinforcements or additional infrastructure.

Part 2. Dynamic study

Data collection and validation

In line with the objectives of the Additional Studies, the dynamic analysis included the transient, small signal and frequency stability analysis performed for the winter peak and summer off-peak scenarios 2020. The load flow and dynamic models were developed for Ukraine and Moldova, the interface countries, and the rest of continental Europe.

The data sources for the models are shown in the map below.

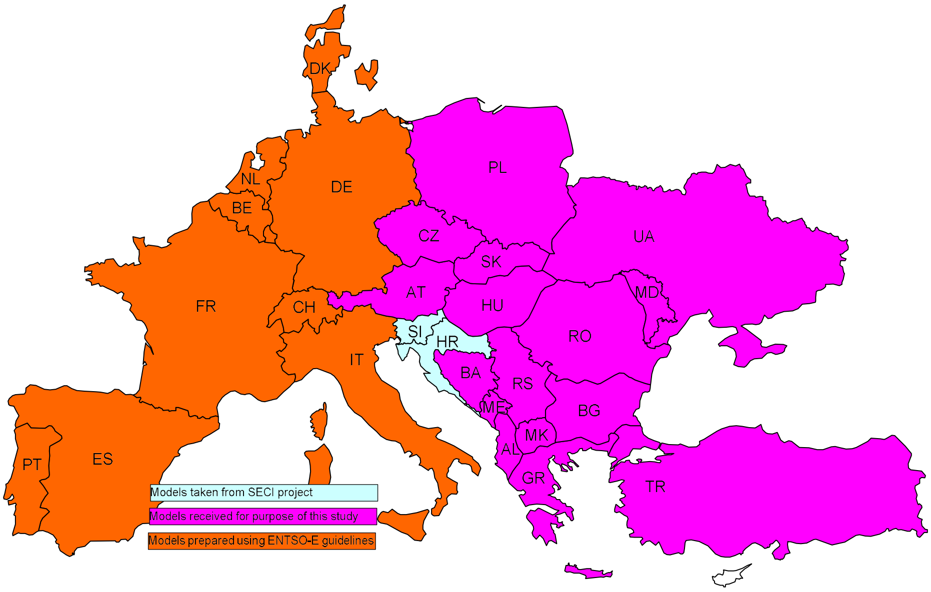

Figure 2 Dynamic models data sources

After the collection process the volume, the dynamic data quality and compliance with the load flow data was found to be satisfactory for both the ENTSO-E part and the Ukraine/Moldova part.

Validation of the CESA models

Validation of the developed dynamic models included validation of the exact models provided by TSOs of the interface area and validation of the entire CESA model.

Taking into account all the observations and conclusions regarding the developed ENTSO-E CE dynamic model, it was stated that the model was validated and adequate to perform the scope of the analysis foreseen in the Additional Studies.

Validation of Ukraine and Moldova models

The validation of the dynamic models for Ukraine and Moldova was carried out for the original models provided by their TSOs. The field test results were used to verify the Ukraine/Moldova Power Factory models and were made available in the test reports.

Taking all the results and conclusions regarding the developed Ukrainian and Moldavian dynamic models, it was stated that the Consortium models can be treated as validated and adequate for performing the scope of analysis foreseen in the Additional Studies.

Validation of the interconnected models

The interconnected models for winter peak and summer off peak scenarios were validated based on expert knowledge about wide-area dynamic phenomena in large power systems. Time domain simulations for loss of large generation in various parts of the connected power systems and modal analysis for low frequency inter-area oscillations have shown that the connected models behave as expected.

Dynamic calculations

The goal of dynamic stability calculations was to assess security and identify possible problems and limitations for the interconnected operation of the power systems in terms of transient and small signal stability. To fulfill this goal, extensive dynamic transient and small signal stability analysis were carried out for the interconnected systems. The analysis covered all possible issues which could affect the dynamic security of the interconnected operation and included both regional and global aspects of dynamic stability.

Regional transient stability

Extensive time domain simulations were performed to verify the regional transient stability behavior of the interconnected system. For the interface countries, Ukraine and Moldova Critical Fault Clearing Times (CCT) were calculated. The calculations were carried out for the pre-connection and post-connection models and for all peak and off-peak load flow scenarios developed by WG1, in which Ukraine and Moldova export/import maximum power, taking into account the n-1 criterion in load flow calculations.

The conclusions of the regional transient stability analysis are as follows:

- All obtained CCT values are above standard clearing times given by the relevant TSOs,
- Results of CCT calculations show that the influence of the connection of Ukraine and Moldova on these values is insignificant. The same applies to the tested power transfers from/to Ukraine and Moldova.

Regional small signal analysis

The analysis included a scan of local oscillations in the interface area. The purpose of the local oscillations scan was to confirm that the interconnection would not deteriorate damping of the existing local electromechanical oscillations in the interface countries and that new poorly damped oscillations would not appear. **The performed calculations did not reveal any threats to the local small signal stability in the interface area caused by the connection of Ukraine and Moldova**.

Inter-area small signal stability

The purpose of the inter-area stability analysis was to investigate the impact of the Ukraine-Moldova connection on the existing low-frequency inter-area electromechanical oscillations and to determine the properties of new oscillations that will appear in the connected systems.

The damping of low-frequency inter-area electromechanical oscillations largely depends on the operating conditions of the system. In accordance with the ENTSO-E practice, the keeping of a 5% margin under the analyzed system conditions (load and generation scenarios, long-distance power transmission, n-1 transmission grid states) was assumed.

The analysis of inter-area small signal stability covered the entire connected system. It was found that Ukraine and Moldova are highly engaged in two inter-area modes which, depending on the interconnected systems conditions, have frequencies ranging from 0.18 Hz to 0.30 Hz. The lower frequency mode (UE1 mode) has lower damping, depends more on the changing system conditions, and generally determines the inter-area stability of Ukraine and Moldova especially for the off-peak scenarios.

The damping of the UE1 mode was calculated for power exports and imports in the range determined by WG1 (up to 2000 MW). The calculations were carried-out for the intact network and for the worst contingencies which were determined to be disconnections of:

- tie line 750 kV Szabolcsbáka (HU) – Zakhidnoukrainska (UA),
- internal Ukrainian line 750 kV Yuzhno-Ukrainska – Vinnytska.

The scenarios with changed power transfers in CESA and scenarios with increased level of renewable generation in Western Europe were considered. In general, it was found that the investigated increase in RES has a smaller impact on the inter-area modes than the change in power transfers that the increase in RES may cause.

In the winter peak scenario, the tested levels of export/import are not limited by the inter-area stability. The assumed damping criterion of a 5% is maintained in whole range of investigated power transfers from/to Ukraine and Moldova in the base scenario, in the scenario with changed power transfers in CESA and in the scenario with increased RES in Western Europe for full grid and for worst n-1 conditions.

In the summer off-peak model, for all export scenarios, including the base case (Ukraine and Moldova exports 600 MW) the UE1 mode has a damping ratio below 5% (4.81% and 4.86% for the worst contingencies). For the modified power transfers in CESA results were worse – the 5% criterion for n-1 network is fulfilled if Ukraine and Moldova import more than 190 MW.

Taking into account the results of the inter-area stability analysis, it is concluded that the connection of Ukraine and Moldova will require actions that will increase the damping of inter-area oscillations with the participation of these countries, especially under light load conditions.

Global transient stability

The investigations performed during wide area transient stability calculations for the interconnected systems included: faults on the tie lines between the interconnected systems, as well as within CESA, sudden loss of generation or load in various parts of the system, sudden disconnection of Turkey power system.

The simulations did not reveal any threats other than poorly damped oscillations involving Ukraine in operating conditions which had previously been identified in the inter-area stability analysis. In particular, during the scanning of the simulation results, no threats were found in terms of voltage and frequency transients (dips and rises) and voltage restoration profiles.

The analysis carried out in this task included scanning the angle difference between buses of the disconnected tie lines and all internal 750 kV lines in Ukraine. It was found that the angle difference of more than 30 degrees can occur between ends of the disconnected 400 kV Vulcanesti (MD) – Isaccea (RO) line in two winter peak scenarios with high power transfers (import 1000 MW or more to Ukraine/Moldova).

Countermeasures

Out of conducted dynamic analysis the only dynamic threat to the safe operation of the connected systems is insufficient damping of low frequency oscillations with a large participation of generators in Ukraine. It was found that these threats occur in off-peak scenarios for power exports from Ukraine / Moldova. Under certain conditions the 5% inter-area oscillation damping limit is not met. Countermeasures necessary to improve the inter-area stability of Ukraine and Moldova in the interconnected power systems were analyzed. This analysis included assessing the effectiveness of existing solutions in the Ukrainian system in terms of damping low frequency oscillations and investigating new potential countermeasures.

Taking into account results of the dynamic analysis it was assumed that the proposed countermeasures should ensure damping better than 5% under the following conditions:

- the worst single contingency which is disconnection of the intertie line 750 kV Szabolcsbáka - Zakhidnoukrainska,
- the power exchange scenarios determined by WG1 in load flow analysis,
- unfavorable (for inter-area stability) power balances in the border areas of CESA.

Considering the obtained results, the proposed solution for improvement of damping of the inter-area oscillations is:

- retuning of selected dual input power system stabilizers (**M1**). The selection should be based on the damping improvement achieved by retuning. Therefore, retuning should apply to units, the generator of which contributes significantly to inter-area oscillations, and at the same time PSS is not properly tuned. It was also found that retuning limited to generators with rated power over 50 MVA (**M1****) may be used with only small decrease of effectiveness.

supplemented with additional measures selected from the following:

- adding of standalone stabilizers to the 1111 MVA nuclear units equipped with REM700 Brushless excitation systems (**M2**),
- AVR retuning on all generators of the nuclear units (**M3**),
- installation of STATCOMs with POD using frequency signal or other power electronics device that could provide equivalent damping (**M4**),
- frequency feedback retuning on generators at Zaporizka NPP (**M5**),
- frequency feedback retuning and AVR gain reduction on generators at Zaporizka NPP (**M6**).

Each of these additional measures ensures a significant and sufficient improvement of the damping of the inter-area oscillations involving Ukraine and Moldova (except M1**+M5 for which the calculated damping may be slightly below 5% for high power exports in CESA). The solution adopted may be a mix of suggested measures.

After applying the proposed countermeasures there are no inter-area stability constraints for maximum power exports from Ukraine and Moldova obtained in the load flow calculations.

Isolated operation

Analysis of isolated operation of electric power systems of Ukraine and Moldova is performed in order to check if UA/MD power system can operate when disconnected from any other system. The main goal of this analysis is to show what can be expected in transition period, when UA/MD power system disconnects from IPS/UPS synchronous area (before its connection to synchronous area of the ENTSO-E CE) as well as what can be expected in case when UA/MD power system is part of ENTSO-E CE synchronous area and the interconnection fails causing UA/MD power system to remain in island operation.

Response of UA/MD power system in isolated operation with initial settings of turbine governors and load self-regulation coefficients is satisfactory for all analyzed outages.

Response to UA/MD power system in isolated operation with reduced FCR and load self-regulation coefficients reduced to 1%/Hz is satisfactory for analyzed outages.

System response is stable, reaching new quasi steady state in reasonable time with small frequency deviation. Load shedding scheme is properly set to cover outage of the largest generating unit. There is no indication of system collapse.

Analysis of isolated operation of electric power systems of Ukraine and Moldova showed that the frequency stability is ensured after loss of investigated infeed and demand.

Conclusion

Taking into account all calculation results and conclusions, it can be stated that from the dynamic stability point of view, the synchronous interconnection of Ukraine and Moldova to ENTSO-E CE is feasible provided that all necessary countermeasures to obtain a sufficient improvement of the damping of low-frequency inter-area oscillations are implemented.