SHORT-TERM FORECAST OF THE ADEQUACY OF THE MONTENEGRIN POWER SYSTEM AS A RESULT OF THE CROSSBOW PROJECT

Aleksandar Petrović
Univerzitet Crne Gore
Aleksandar.Petrovic@ucg.me

Milica Jovanović
Univerzitet Crne Gore
Milica.Jovanovic@ucg.me

Jelena Marković
Univerzitet Crne Gore
Jelena.Markovic@ucg.me

SUMMARY

CROSSBOW is Horizon 2020 funded project and will propose the shared use of resources to foster cross-border management of variable renewable energies and storage units, enabling a transnational wholesale market. Montenegrin power system (CGES) has become a part of CROSSBOW consortium, which is composed of 24 members, recognized as end user of final project results, with intention to define requirements, validate and demonstrate the results. One of the results of the project, whose functionality will be presented in this paper, is a software solution that will help with coordination, interaction and exchange system reliability data between the transmission system operators in the region. The power system can be considered reliable if the conditions of adequacy and safety are fulfilled. Through this paper, the results of the probabilistic approach in the short-term forecast of the adequacy of the Montenegrin power system will be presented, also the ability of the system to meet the needs of consumption from domestic sources of electricity and imports from neighbouring systems.

Key words: short term forecast, adequacy, probabilistic approach

1. INTRODUCTION

One of the results of the CROSSBOW project, whose functionality will be presented in this paper, is a software solution through which the Regional Security Coordination Centre (RSC) will perform coordination, interaction and exchange of data on system reliability between transmission system operators (TSO) from the region, where the cooperation will be enhanced and the quality of services will be improved including the possibility to develop new services referring to integration of renewable energy sources, cross-border management and storage of energy. As in the past years big changes have occurred in the structure of the Montenegrin power system, especially due to the connection of renewable sources, space has been created to test modern probabilistic approaches for adequacy forecast in parallel with the current deterministic approach. By engaging the CROSSBOW project, Crnogorski elektroprenosni sistem (CGES) expressed special interest in testing the probabilistic approach in the short-term forecast of the power system adequacy whose results will be shown below.

2. CROSSBOW PROJECT

The CROSSBOW project is part of the HORIZON 2020 programme funded from the budget of the European Commission dedicated to research and innovation in areas where it is necessary to find new, good solutions and remove numerous challenges. HORIZON 2020 represents the biggest funding system (the budget is about €80 billion) for the needs of science and innovation in the world with the aim of making the science on European soil competitive with respect to the rest of the world. The programme offers donations to entities from all sectors – academic community, state institutions, industry, small and medium-sized enterprises, associations, non-governmental organisations etc. in order to focus more intensively on innovations and scientific research activities close to the market. It consists of three pillars: Excellence in Science, Industrial Leadership and Social Challenges [1]. The consortium of the CROSSBOW project applied to the call in the field of Social Challenges and has the task to establish the cross-border management of renewable energy sources and storage units in order to ensure an international electricity market in large. The objective of this project, after 48 months how long it will last, is to provide services to representatives of transmission networks in various scenarios, in order to promote sustainable electrical networks that contain a bigger penetration of renewable energy sources in the total generation and provide the possibility to establish pan-European balance electricity market close to real time. Spanish company ETRA is at the head of the consortium, and in addition to energy companies (EMS, NOS BIH, MEPSO, HOPS, ADMIE, ESO, TRANSELECTRICA, CGES, SCC, CRE, ELEM, EPS, CGRID, PPC, COBRA, HEDNO), the CROSSBOW consortium consists of successful companies engaged in the production of software (KONČAR, ELPROS, ICCS) and batteries (VARTA), as well as university units (UNIMAN, UL, UKIM, UNIZG, UCG). In addition to the fact that successful companies in the field of energy and electronics work in this project, the total value of the consortium's activities, which amounts to about €22 million, contributes also to the significance of the projects.

CGES approached the CROSSBOW consortium as the final beneficiary of the results of the project, where in cooperation with neighbouring system operators will ensure testing, validation and demonstration of results obtained through this project. CROSSBOW technologies shall be contained in 8 different solutions (results):

1. Providing bases for establishing Regional Operational Centres (ROCs) in Southeast Europe;
2. Creation of regional centres for coordination between TSOs and renewable energy sources;
3. Integration hybrid manageable renewable sources in the existing network;
4. Creation regional centres for coordination of electricity storages;
5. Construction of systems of virtual plants for electricity storage;
6. Implementation of systems of supervision and caution in a wide area;
7. Establishing a regional platform for consumption management;
8. Defining markets of ancillary services and wholesale trade.

The previously shown results will be tested through 9 testing groups (High Level Use case – HLU), given in the figure below, together with relations between the mentioned objectives and planned solutions of the CROSSBOW pr

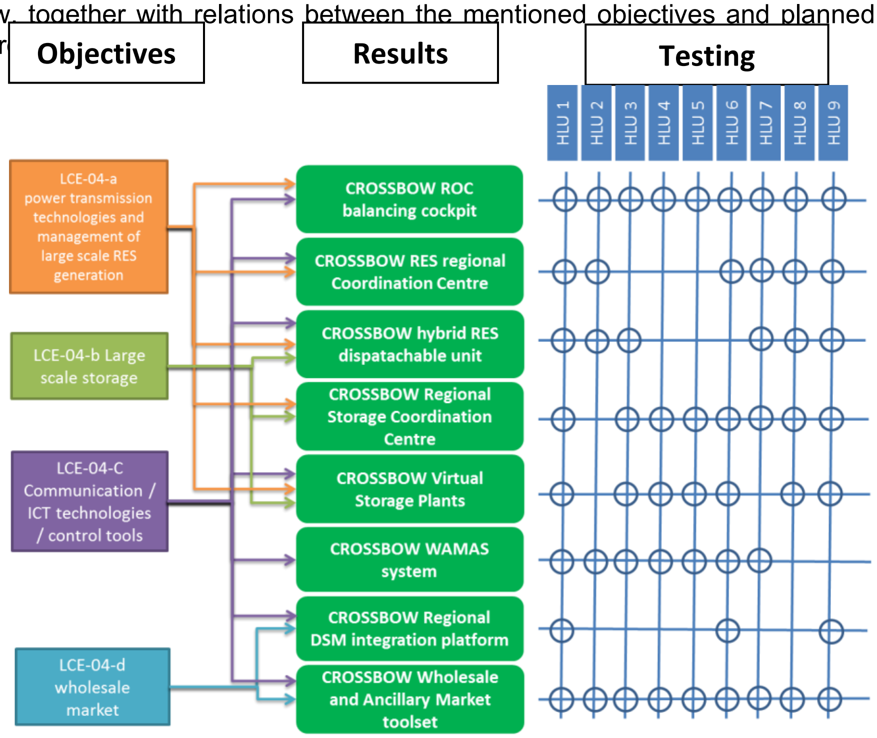

Figure 1. Organisation of testing groups for achieving results in order to realise the objectives of the CROSSBOW project

By approaching the CROSSBOW project, CGES joined the team that will provide, though a four-year research, support to the implementation of the project by making available its resources and technology in order to test and demonstrate results for the needs of the project. In accordance with technical capabilities, CGES participated in testing groups that refer to establishing a regional operational centre (HLU 1), coordination between TSOs and renewable energy sources (HLU 2), the development of consumption management platform (HLU 6) and defining conditions for establishing markets of ancillary services and wholesale trade (HLU 9). One of the objectives of this project is to provide bases for establishing ROCs in the area of Southeast Europe. It has been envisaged that ROC, in addition to 5 basic activities of RSC prescribed by ENTSO-E (European Network of Transmission System Operators for Electricity) – security analysis, short-term and medium-term adequacy forecast, calculation of capacity, plans of disconnection and network models, will assume responsibility also for the following activities: coordination of ancillary services and consumption management, with the aim of allowing with this solution higher exchange of information between TSOs in order to increase efficiency and reliability of the system. Since the integration of renewable sources is constantly increasing, the platform that will allow coordination between TSOs and renewable sources represents an especially significant result of this project. This implies tools for the forecast of consumption and generation as well as an overview of the current state (real time) of generation and consumption in interaction with neighbouring TSOs. The objective of this solution is to give priority to renewable sources in generation. Not so popular but yet technically feasible possibility is the participation of consumption units in the process of providing ancillary services. One of the basic obstacles for using this service is a very high price of engaging consumption capacities for the needs of system balancing, but how it is technically feasible, CGES expressed interest in carrying out experiments aimed at analysing energy parameters when disconnecting the most significant elements in the system. In addition to consumption management for the purpose of system balancing, priority is given to the market of ancillary services and wholesale trade, so the idea is, in order to receive more favourable offers, to develop a platform in accordance with the defined rules, where traders and TSOs will perform services of provision and demand of energy for balancing based on the blockchain technology.

Considering that CGES' engagement in the project is voluminous and demanding, only one tool will be processed in this paper that will be implemented within the testing group HLU 1, and it will serve for the needs of short-term adequacy forecast. This paper proposed a different forecast approach which, unlike the current deterministic approach, is based on the probabilistic methodology.

3. ADEQUACY FORECAST

Power system reliability is a mathematical probability that the system will operate satisfactorily in a certain time period with both envisaged and defined operating conditions. It has two main aspects: adequacy and security. Adequacy represents an assessment of capability of a certain power system to meet its own consumption with its available generation and import of electricity from neighbouring countries.

According to the ENTSO-E adequacy assessment methodology (Project Group SMTA), if TSO's inadequacy is shown, the possibility of importing energy from neighbouring countries that have a surplus of available generation is checked in order to find a solution for the inadequacy, where the availability of cross-border transmission capacities is taken into consideration. Each TSO receives the results of such methodology from the Regional Coordination Centre in form of a weekly report for the interregional short-term adequacy forecast.

3.1 Deterministic and probabilistic approach

Methods for system adequacy calculation have been categorised as: deterministic and probabilistic. Deterministic methods are based on the analysis of just a few system scenarios that have been selected as the most representative in situations that can lead to a critical operation of the system. Such method allows assessing the impact of specific situations on reliability, but it cannot assess the total reliability of the system. The determinists approach usually implies a shortened time of calculation and management of data, however, as a defect, it requires a good knowledge of the power system that is analysed because TSOs must first identify specific states of the power system based on their experience. There are several problems with this approach:

- It considers only a few results based on criteria of analysis, neglecting hundreds or thousands of others;
- It gives equal weight to each final result. Namely, with this method it is not possible to assess the probability of occurrence of each final result;
- The interdependence between input data, as well as the impact of various input data on final results, are ignored, with the risk of simplifying the model and thereby reducing its accuracy;
- It is impossible to consider combinations of unfavourable generation resources such as wind or water with failures in generation facilities or overhead lines – a very probable event in systems with high penetration of renewable energy sources.

However, despite its defects, many organisations work with this type of analysis by integrating also the approach of the probabilistic model in order to assess more precisely specific cases and scenarios.

The probabilistic criteria represent the generalisation of the deterministic approach because, in principle, all possible limiting situations are tested and risk indices are obtained from them. In these terms, several potential values of the remaining capacity are considered due to possible variations of generation from renewable sources and consumption depending on weather conditions [2]. This approach endeavours to consider in a realistic and coherent manner the insecurities in terms of consumption, wind and photovoltaic solar supply that may impact on the security of supply and simulate several different realistic scenarios. Therefore, the selected approach represents the probabilistic manner of modelling of variables that refer to the wind and solar generation, as well as to load. Other types of generation and variables needed for the process are assessed by TSOs in the following week by the deterministic method.

The main defects of the deterministic approach, which are solved with the probabilistic method, are [3]:

- There are no limitations in the selection of scenarios and unforeseen circumstances; the only limitation was performed from the maximum number of tested situations;
- The possibility of allocation different weight to each case, which is studied based on its probability of occurrence;
- Better image of the stochastic nature of the power system and enabling a more quality modelling of insecurities that appear during planning.

The probabilistic modelling of power system adequacy passes through three phases (Figure 2) [4]:

1. Generation/consumption model;
2. Combination of generation and consumption model to obtain a system balance model;
3. Calculation of adequacy index (SAI).

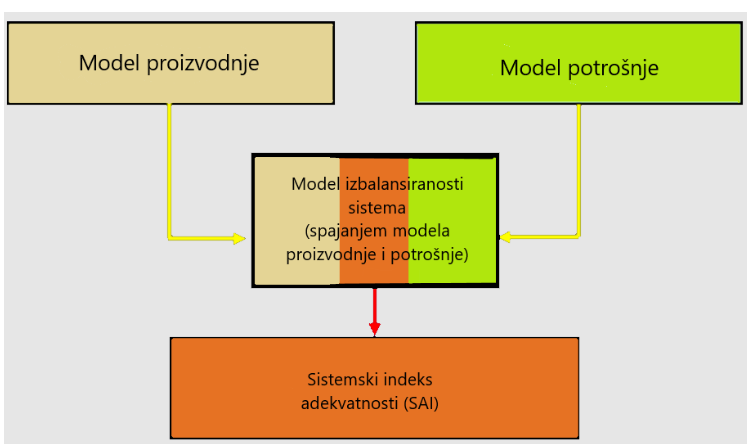

Figure 2: Probabilistic modelling of power system adequacy

4. CROSSBOW PROBABILISTIC MODEL FOR SHORT-TERM ADEQUACY FORECAST

For the needs of functioning of the RCO, envisaged by the project, within the testing group HLU 1, a platform shall be developed which, in addition to previously defined functionalities, will have the possibility of performing short-term adequacy forecasts on the probabilistic model principle. PROMESA (Probabilistic Modelling and Evaluation of System Adequacy) is a software solution that will be used for medium-term and short-term adequacy forecast and for modelling of the availability of power system capacity with the aim of implementing it as one of the functionalities of the results of HLU 1.

During the probabilistic modelling of adequacy, it is first necessary to define some basic units that are used [4]:

- LOLP (loss of load probability) – the probability that the availability of the total capacity will not be enough to meet the needs of consumption *L* in the observed hour *h*;
- LOLE (loss of load expectation) – the number of hours in the time period T when the availability of the total capacity is not enough to meet the needs of consumption:

$$LOLE_T = \sum_{h=1}^{T} LOLP_h \tag{1}$$

- SAI – System adequacy index:

$$SAI= 1\text{-}LOLP \tag{2}$$

The probabilistic modelling of generation is based on the Mark's model (Figure 3) that represents the simplest probabilistic model where one generator unit is described with two states:

- In operation – unit is available for generation;
- Out of operation– outage of generator unit.

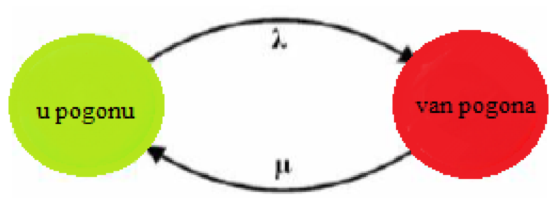

Figure 3: Mark's model

Parameters that describe the mentioned generator state are the speed of disconnection (λ) and connection (μ) [5]:

$$\lambda = \frac{1}{MTBF} \tag{4}$$

$$\mu = \frac{1}{MTTR} \tag{5}$$

where $MTBF$ is the average value (in hours) between outages, and *MTTR* the average-hour value until connection. A long-term adequacy state can be determined by the abovementioned relations by calculating coefficients *p* and *q*, which represent the state of a generator unit in operation and out of operation, respectively (steady-state):

$$p = \frac{\mu}{(\lambda + \mu)} \tag{6}$$

$$q = \frac{\lambda}{(\lambda + \mu)} \tag{7}$$

The probabilistic function for the calculation of total capacity C_{TOTAL} is $f_{TOTAL}(C_{TOTAL})$ and it represents the convolution of the probabilistic function for conventional sources $f_1(x)$ and the probabilistic function for the remaining capacities $f_2(z-x)$ (unconventional):

$$f_{TOTAL}(z) = \sum_{x=1}^{z} f_1(x) * f_2(z-x) \tag{8}$$

Based on the mentioned relation, the probabilistic generation model is obtained that gives more precise data, particularly for the short-term adequacy forecast.
The calculation of models of system balance represents the difference between the total forecasted capacity and envisaged consumption for the observed hour [4]:

$$B_h^{SYSTEM} = C_h^{TOTAL} - L_h \tag{9}$$

The probabilistic calculation of system balance represent the convolution of the probabilistic function of the total capacity C_{TOTAL} and the probabilistic function of consumption L_h:

$$f_{BALANCE}(z) = \sum_{x=-C_{inst}}^{z} f_{C_{inst}}(x) * f_L(z-x) \tag{10}$$

where $z = -C_{inst}, \ldots, C_{inst}$ i C_{inst} is the total installed power of generation capacities in the system.

4.1. CROSSBOW software – PROMESA

Within the CROSSBOW project and in cooperation with the Bulgarian TSO (ESO), results were obtained for short-term adequacy forecast for the needs of the Montenegrin power system. On this occasion, the application based on Microsoft Excel – PROMESA was used.
The proposed calculation (formulas 8, 9, 10) was implemented through a software that gives as result the short-term adequacy forecast (seven days in advance). For the needs of developing a model of adequacy of the Montenegrin power system, input data from the system were collected. The evaluation was done for the period from 1 December 2018 to 7 July 2018 in hour resolution. According to Figure 4, it can be seen the result of LOLP value for conventional generation capacities, based on input data submitted by CGES.

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power plant	unit №	Pava, MW	FOR, %	λ	μ	1	2	3	4	5	6	7	8	9	10	11	12	
TPP Pljevlja	1	205	6.2	0.00183831	0.00250000	0.000268	0.000536	0.000802	0.001067	0.001330	0.001593	0.001855	0.002115	0.002374	0.002632	0.002889	0.003145	0
HPP Mratinje	1	114	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	2	114	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	3	114	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
HPP Perucica	1	36	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	2	36	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	3	36	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	4	36	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	5	36	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	6	59	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0
	7	59	1.0	0.00014957	0.00438889	0.000045	0.000090	0.000135	0.000180	0.000224	0.000269	0.000313	0.000357	0.000400	0.000444	0.000487	0.000530	0

Figure 4: Calculation of LOLP value

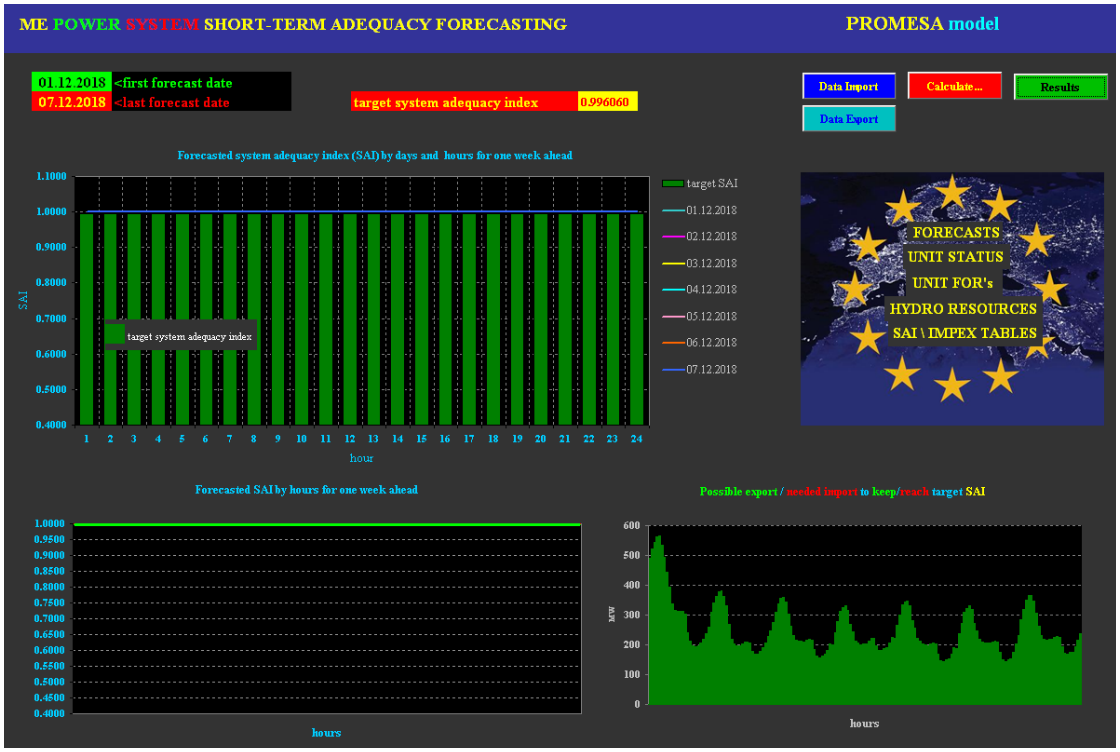

Figure 5: Graph of SAI coefficient

Figure 5 contains the graph of the set SAI coefficient, which represents the reference value defined in advance (in this case it amounts to 0,996) and the calculated SAI coefficient that is obtained with the probabilistic calculation based on input data. As an input data, Figure 6 shows the numeric values of the SAI coefficient as well as energy values for each day in hour resolution, where the possible export is marked in green (the calculated SAI coefficient is above the reference value) while the necessary export of electricity is marked in red (the calculated SAI coefficient is below the reference value).

target system adequacy index 0,996060 BACK TO INTRO

Estimated system adequacy indices by days and hours for the forecast period

date \ hour	1	2	3	4	5	6	7	8	9	10	11	12
1.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
2.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
3.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
4.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
5.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	0,999999	0,999999	0,999999
6.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	0,999999	0,999999	0,999999
7.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	0,999999	0,999999	1,000000

date \ hour	13	14	15	16	17	18	19	20	21	22	23	24
1.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
2.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
3.12.2018	1,000000	1,000000	1,000000	1,000000	1,000000	0,999999	0,999999	0,999999	0,999999	1,000000	1,000000	1,000000
4.12.2018	1,000000	1,000000	1,000000	1,000000	0,999999	0,999999	0,999999	0,999999	0,999999	1,000000	1,000000	1,000000
5.12.2018	0,999999	0,999999	0,999999	0,999999	0,999998	0,999996	0,999995	0,999996	0,999997	0,999998	0,999999	0,999999
6.12.2018	0,999999	0,999999	0,999999	0,999999	0,999998	0,999995	0,999993	0,999995	0,999996	0,999998	0,999999	1,000000
7.12.2018	1,000000	1,000000	1,000000	1,000000	0,999998	0,999997	0,999997	0,999997	0,999997	0,999998	0,999999	1,000000

system adequacy index above target level

system adequacy index below target level

POSSIBLE EXPORT KEEPING THE TARGET SAI <<<<<<<< >>>>>>>> NEEDED IMPORT TO REACH TARGET SAI

date \ hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.12.2018	490	522	545	564	565	534	493	445	395	338	316	311	312	313	302	240	213	196	193	198	205	220	238	260
2.12.2018	310	341	363	379	381	364	330	269	219	203	197	196	202	209	208	205	178	170	169	177	191	207	227	247
3.12.2018	274	309	339	356	360	345	304	261	230	216	211	212	210	215	220	216	184	164	157	164	168	182	202	200
4.12.2018	242	278	313	325	330	316	268	245	214	205	201	202	204	213	221	223	197	182	182	188	191	207	226	221
5.12.2018	265	300	333	344	347	332	282	255	223	211	203	200	198	203	206	202	170	148	144	150	153	170	191	189
6.12.2018	236	273	308	322	330	318	271	248	219	210	206	205	205	210	213	208	175	150	144	151	153	175	202	231
7.12.2018	285	320	349	366	367	348	307	264	231	218	215	219	220	225	228	225	193	172	168	174	176	193	215	237

Figure 6: Output data, results of short-term adequacy forecast

5. CONCLUSION

Adequacy represents an assessment of capability of a certain power system to meet its own consumption with its available generation and import of electricity from neighbouring countries. As one of the final beneficiaries of the CROSSBOW project, CGES took the role of testing the software for the needs of short-term adequacy forecast, where final results were obtained based on real input data (planned and realised) from the Montenegrin power system. The testing was performed based on the comparison of the defined, reference system adequacy index and calculated index, obtained by the probabilistic modelling of input data. The results of the probabilistic model showed that a more precise image of the stochastic nature of the power system and enabling a more quality modelling of insecurities that appear during planning. The shown results were obtained in cooperation between the Bulgarian TSO (ESO), Security Coordination Centre (SCC) and Crnogorski elektroprenosni sistem (CGES) within the research CROSSBOW project.

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