Journal of Energy

VOLUME 67 Number 3 | 2018 Special Issue

journal homepage: http://journalofenergy.com/

Goran Majstrovic
Drazen Jaksic
Martina Mikulic
Davor Bajs
Energy Institute Hrvoje Pozar
Croatia

William Polen
Albert Doub
United States Energy Association
USA

Impact of Adriatic submarine HVDC cables to South East European Electricity Market Perspectives

SUMMARY

The ultimate goal in today's electricity business in Europe is market integration on pan-European level that will introduce transparency and competition between market players, incentives to clean energy development, as well as high quality of supply to the end-customers. To achieve these goals, in South-East Europe (SEE) there are number of barriers and uncertainties, one of which is linked with the possible new undersea HVDC connections between SEE and Italy.

With the support of the United States Agency for International Development (USAID) and coordination of the United States Energy Association (USEA), within the framework of the Southeast Europe Transmission System Planning Project (SECI), a detailed analysis has been accomplished on the impact of one or more undersea HVDC cables between Italy and SEE on power system operation and electricity market development [1]. Special emphasis to this analysis is given by the fact that SECI has been one of the longest running projects in the region. It started in 2001 with active participation of all regional TSOs, including continuous updating of power system and electricity market models and its harmonization of constant changes in power system planning. It is of utmost importance in the environment of constant changes of national power system development plans and needed further steps for full market opening and integration in the region.

SEE power systems and market[1] were modelled using the most relevant power system and market simulation and optimization softwares. Both system and market comprehensive models have been verified by all SEE TSOs.

Study analyses were divided in two parts: 1) market analysis and 2) network analysis. The market study investigated expected generation pattern, power exchanges and wholesale prices in SEE, taking into account regional market synergy, the new links with Italy, and high level of RES integration. Bulgaria and Romania are currently the main exporters in SEE. Significant power exchanges in the North-South/Southeast direction are related to the fact that the GR, MK, ME, HR and AL are mainly importing, plus the influence of Italy importing over new potential HVDC cable(s). Network analysis dealt with power flows, network bottlenecks and voltage profiles in given market scenarios.

Finally, the results of this comprehensive market simulation comprised of the following:

- Countries electricity balance (production, consumption and exchanges)
- Electricity prices for each country
- Cross-border power exchanges (MWh/h) for each border in the region on hourly basis
- HVDC link loadings (MWh/h) for each HVDC submarine cable on hourly basis
- Location and frequency of market congestions in SEE (NTCs full between areas with price difference)

All those analyses have been performed in two different transmission network development scenarios:

- Base case scenario: with planned HVDC ME-IT
- Alternative scenario: with planned HVDC ME-IT, and HVDC HR-IT, and HVDC AL-IT

In this way one of the most important uncertainties (new HVDC links SEE – Italy) for future power system and market operation in SEE, have been evaluated both in technical and market sense, using the most relevant inputs and model.

KEYWORDS

South East Europe, HVDC submarine links, Italy, electricity market

1 Albania (AL), Bosnia and Herzegovina (BA), Bulgaria (BG), Greece (GR), Croatia (HR), Hungary (HU), Kosovo (KS), Montenegro (ME), Macedonia (MK), Romania (RO), Serbia (RS), Slovenia (SI).

INTRODUCTION

The case of new HVDC links between SEE (net exporter) and Italy (net importer) is relatively unique since we have two parallel uncertainties behind these large infrastructure investments that could change current electricity market positions: 1) strong development of SEE regional market and uncertain development of new generation portfolio and 2) strong development of generation (primarily RES) in Italy and potential change of existing country (importing) balance. The main target of this study was to evaluate impact of new HVDC links SEE – Italy on the future, expected electricity market and network in the region. The project has been divided in two phases:

1) preparation of common electricity market and power system model
2) detailed market and network analyses

In the first phase, relevant input data were collected, clarified and verified. It lasted for almost a year. The second phase aimed to assess perspective electricity market and system behavior in SEE considering influence of generation development involving RES, markets integration and the subsequent transmission investments.

SOUTH EAST EUROPEAN ELECTRICITY MARKET AND POWER SYSTEM MODEL

The primary source of model input data has been provided by all regional TSOs, which is of utmost importance due to all market and network planning uncertainties [2]. For the remaining unavailable data, other verified and publicly available official data (e.g. ENTSO-E Pan European Market Modelling Database [3]) have been used along with internal documents and estimates. To perform market analysis SEE power systems have been modelled with electricity market simulation and optimization software PLEXOS, while for the network analyses PSS/E software platform was used. Starting with the data collected from the TSOs, the following modelling approach has been adopted for each country:

- Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Kosovo, Macedonia, Montenegro, Romania and Serbia are modelled on plant-by-plant level of details,
- Greece, Hungary and Slovenia are aggregated per technology clusters (thermal by fuel type, hydro by type, RES by technology),
- Italy, Turkey and Central Europe region are modelled as external spot markets where the market clearing price series is insensitive to fluctuations of prices in SEE, constrained by transmission capacity.

Target year for these analyses was set to 2030 and the simulations have been carried out on hourly basis. Annual electricity demand was modeled on hourly basis. The generation cost function was also modeled, together with constraints of generation dispatch (must-run units, weather conditions, etc.). Market and grid models maintained compatible to run iteratively.

Considering the size of simulated system and the amount of collected data, each national market has been modelled as a single equivalent node to which all generators within the country were connected to. Nodes were connected by virtual transmission lines with maximum capacity equal to the nominal transfer capacities between the two countries.

Market model consists of 580 generating units in 12 SEE countries. It refers to 153 thermal power plants (TPPs), 6 nuclear power plants (NPPs), 124 storage hydro power plants (HPPs), 53 run-of-river (RoR) HPPs. Accordingly, this is the most detailed electricity market model in the region, verified by all TSOs. In addition, for each country one equivalent wind and one equivalent solar power plants have been modelled. Three external markets representing Italy, Turkey and Central Europe have also been modelled using simulated hourly price time series. This market model contains 28 cross-border lines and 4 submarine HVDC cables.

On the other side, regional power system model consists of more than 5500 nodes, 2000 power plants, 2200 generators, 9000 lines and 2800 transformers. It is the most detailed SEE power system model ever prepared.

ELECTRICITY MARKET AND NETWORK DEVELOPMENT SCENARIOS

Impact of new regional candidate connections towards Italy was assessed by analyzing three scenarios, as shown on the following Figure:

1) Reference Case scenario: with existing HVDC Greece-Italy

2) Base Case scenario: with existing HVDC Greece-Italy and HVDC Montenegro-Italy (under construction)

3) Alternative Case scenario: with existing HVDC Greece-Italy, HVDC Montenegro-Italy (under construction), HVDC Croatia-Italy and HVDC Albania-Italy

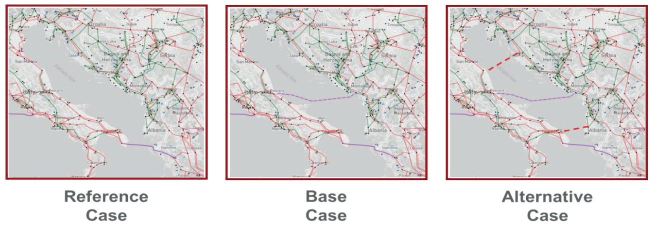

Figure 1: Illustration of analyzed scenarios

Reference Case scenario was created for comparison of the Base and Alternative Case scenario results. Reference Case scenario includes only the existing HVDC cable Greece-Italy and thus it presents current status of the regional interconnections to Italy. Base and Alternative Case scenario results are compared in terms of yearly electricity generation, average wholesale prices, net interchange, total transfer and cross-border loadings.

Important aspect of the market analysis lies in CO_2 emission prices that have also been included in the optimization objective function. Assumption on CO_2 emission prices is taken from ENTSOe Ten Year Network Development Plan 2016 [4] with the value of 17 €/ton. Additional set of scenarios (Reference, Base, Alternative) without Carbon Costs has also been analyzed for the evaluation of the effect of CO_2 emissions prices.

Network analyses have been based on the Market Analysis snapshots. For the Base Case and Alternative Case scenarios three study cases have been analyzed:

1) Highest consumption in SEE (18th of December 2030, 18:00h)
2)Highest RES penetration in SEE (9th of December 2030, 11:00h)
3) Lowest Consumption in SEE (28th May 2030, 03:00h)

Those three system snapshots have been identified as the most critical in terms of transmission system operational security. For two scenarios (Base and Alternative) and three characteristic regimes, total of six network (load flow) models have been created for the network analyzes. As a starting point SECI regional transmission system model (RTSM) for 2030 Winter Peak regime has been used.

ELECTRICITY MARKET ANALYSES RESULTS

Regional wholesale prices are determined by marginal cost of generation and price on the external markets. These prices are comparable to actual market prices (due to input data and assumptions on fuel costs, generation cost curves, generation investments and demand increase, etc.). In SEE region wholesale electricity prices are mainly harmonized, with certain variations (for example in Greece). It assumes practically fully integrated SEE electricity market although several network congestions are still existing in the region.

Study results show that average market price in SEE is increased by 1.60 €/MWh in the Base Case and 3.75 €/MWh in the Alternative Case compared to results of the Reference Case, as shown on the following Figure. Thus, it can be concluded that additional HVDC links to Italy increase wholesale prices in SEE region up to 10%, but they also increase electricity generation and revenues.

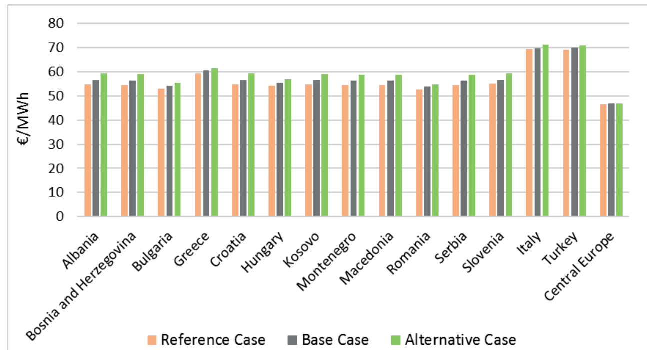

Figure 2. Comparison of average wholesale prices

Total generation in SEE is increased by 3.35 TWh (0.96%) in Base Case and 8.98 TWh (2.58%) in Alternative Case, compared to Reference Case scenario, as shown in the following Table. The most significant change occurs in Bosnia and Herzegovina – in Base Case yearly generation is increased by 1.53 TWh compared to Reference Case, while in Alternative Case by 3.51 TWh. Certain increase of electricity generation can be also expected in Bulgaria, Romania and Serbia.

Table 1: Comparison of electricity generation in SEE region on country basis

Yearly generation (TWh)	AL	BA	BG	GR	HR	HU	KS	ME	MK	RO	RS	SI	TOTAL
Reference Case	10.75	15.59	50.99	51.11	15.06	40.04	12.07	4.57	10.42	88.44	35.18	14.31	348.53
Base Case	10.74	17.11	51.30	50.99	15.24	39.93	12.07	4.57	10.66	88.85	36.10	14.31	351.88
Change (TWh)	-0.01	1.53	0.32	-0.11	0.18	-0.11	0.00	0.00	0.24	0.41	0.92	0.00	3.35
Change (%)	-0.12	9.79	0.62	-0.22	1.18	-0.27	0.00	-0.01	2.33	0.46	2.61	0.01	0.96
Alternative Case	10.79	19.09	51.61	51.89	15.52	40.21	12.06	4.66	11.04	89.36	36.95	14.32	357.50
Change (TWh)	0.04	3.51	0.62	0.78	0.45	0.17	-0.01	0.10	0.62	0.92	1.77	0.01	8.98
Change (%)	0.36	22.50	1.22	1.53	3.02	0.43	-0.11	2.09	5.99	1.04	5.03	0.04	2.58

As expected, additional HVDC cables in the Base and Alternative Case increase net interchange to Italy. Italy is a net importer and in the Base Case scenario Italy imports 5,214 GWh more than in Reference Case, while in the Alternative 12,652 GWh more than in the Reference Case. With new HVDC link SEE region will become a stronger net exporter in the Base and Alternative Case. In the Base Case net interchange of SEE region is 3,284 GWh higher than in Reference Case, while in the Alternative Case it is 8,753 GWh higher than in the Reference Case.

Effect of CO_2 emission prices has been evaluated in additional set of scenarios without carbon cost. In all scenarios without carbon cost, electricity generation is expectedly increased. In the Base Case total SEE generation is 14.49 TWh higher, in the Alternative Case 14.52 TWh higher than in the main set of scenarios with Carbon Costs included. In scenarios with no carbon cost, the cost of generation is lower and thus market prices in SEE are lower. Average wholesale price in SEE region in scenarios without carbon cost is 5.60 €/MWh lower in the Base Case and 3.84 €/MWh lower in Alternative Case, which is quite significant. Based on the market analyses, the main findings of the network analysis are given as follows.

ELECTRICITY NETWORK ANALYSES RESULTS

The analyses have shown that for some countries level of power exchanges presumed in initial SECI RTSM development model are different than the ones obtained from the Market Analyses in this study, i.e.:

- For Albania, Montenegro, Serbia and Slovenia, market analysis has shown these countries are importers rather than exporters, as it is initially individually expected
- For Greece and Macedonia, market analysis has shown these countries are exporters rather than importers, as it is initially presumed
- For other countries considered, initially planned exports or imports are in line with Market Analysis results, just with different total amounts

This brings us to the first conclusion: planned generation investments in all regional countries in given timeframe will significantly change individually expected country balances. Because of different exchange levels, load flow patterns will also be different. When compared to initial SECI RTSM 2030 Winter Peak model, main expected differences in power exchanges are the following:

- Flows from Hungary to Croatia are increased from 850 MW in the Base Case, to 1150 MW in the Alternative Case
- Flows from Romania to Serbia are increased from 600 MW in the Base Case to 1150 MW in the Alternative Case
- Flows from Greece to Albania are increased from 600 MW in the Base Case to 800 MW in the Alternative Case
- Flows from Bosnia and Herzegovina towards Croatia are decreased by 500 MW in the Base Case and increased by 500 MW in the Alternative Case.
- Flows in all analyzed regimes are in direction from Bosnia and Herzegovina to Montenegro, while it is opposite in SECI RTSM model
- Flows in all analyzed regimes are in direction from Greece to Macedonia, while it is opposite in SECI RTSM model

Finally, the biggest cross-border flow differences between SECI RTSM model and models based on market studies are shown on the following Figure.

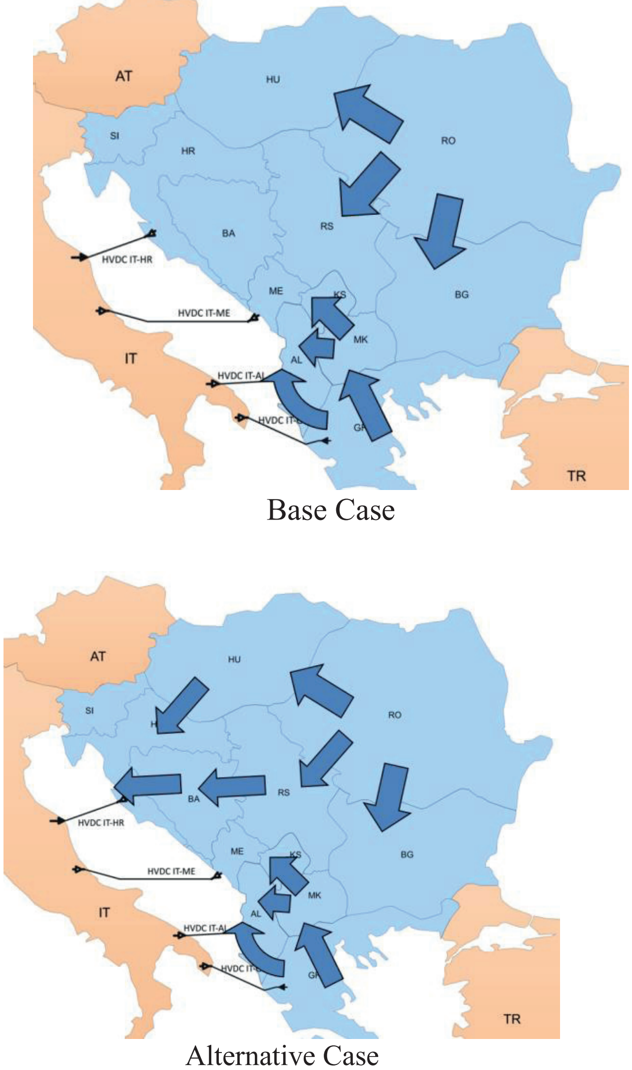

Figure 3: The biggest cross-border flow differences between SECI RTSM model and models based on market studies

For all above mentioned scenarios and characteristic regimes, load flow calculation, voltage profile assessment and (n-1) contingency analysis were carried out. Also, for significant planned projects in the region, TOOT analysis was additionally conducted, with the aim of evaluating their influence on overall security of the transmission network in SEE region, in market coupled conditions. TOOT (Take Out One at the Time) method consists of excluding grid element projects from the forecasted network structure on a one–by–one basis and to evaluate the load flows over the lines with and without the examined network reinforcement (a new line, a new substation, a new PST etc).

For all Base Case regimes, it was generally concluded that market coupling in SEE region introduced changes in load flow patterns. Changes in power flows in transmission networks of the SEE region will not lead to the network overloading if all network elements are available. In such network topology conditions, voltage levels will also be within allowed limits for Highest Consumption and Highest RES penetration regimes. For Lowest Consumption regime, the voltages are out of allowed limits and additional reactive compensation measures will need to be implemented to decrease high voltages.

Market simulations for Base Case scenarios have shown big congestions, with program flows reaching NTC values for many hours. Grid analyses have shown that, in terms of (n-1) security criteria assessment, Highest RES penetration regime was identified as the most critical one for the Base Case scenario. In this regime, outage of 400 kV OHL Portile de Fier (RO) – Resita (RO) causes overloading of 400 kV OHL Djerdap (RS) – Portile de Fier (RO). For other two regimes, Highest Consumption and Lowest Consumption, transmission networks in SEE region satisfy (n-1) security criteria.

Sensitivity analysis has been conducted for several planned projects by applying TOOT methodology. The results are as follows:

- Project 400 kV OHL Pancevo (RS) – Resita (RO) has shown significant influence on (n-1) security criteria, in Highest Consumption and Highest RES penetration regimes
- Project 400 kV OHL Banja Luka (BA) – Lika (HR) has shown small influence on (n-1) security criteria, in all analyzed regimes
- Project 400 kV OHL Bitola (MK) – Elbasan (AL) has shown small influence on (n-1) security criteria, in all analyzed regimes
- Project new 400 kV interconnections RS-BA-ME has shown small influence on (n-1) security criteria, in all analyzed regimes

On the other side, for all Alternative Case regimes, it was generally concluded that market coupling in SEE region also introduces changes in load flow patterns. Changes in power flows in transmission networks of the SEE region did not lead to overloadings if all network elements are in operation. Under these conditions, voltage levels were in permitted ranges for Highest Consumption and Highest RES penetration regimes. For Lowest Consumption regime again, additional reactive compensation measures will need to be implemented to decrease unacceptable high voltages.

In terms of (n-1) security criteria assessment, Highest Consumption regime was identified as the most critical one for Alternative Case scenario. In this regime, outage of 400 kV OHL Konjsko (HR) – Mostar (BA) and outage of 220 kV Konjsko (HR) – Zakucac (HR) are causing overloading of 220 kV OHL Zakucac (HR) – Jablanica (BA). For other two regimes, Highest RES penetration and Lowest Consumption, transmission networks in SEE region satisfy (n-1) security criteria.

Reported congestion on Croatia-BiH border in Highest Consumption regime, is a strong signal that in order to introduce estimated or higher levels of NTCs for target year between these two countries, additional network reinforcement has to be implemented to enhance electricity trade and to support higher social welfare (lower overall price). Sensitivity analysis conducted for several projects with TOOT methodology has shown that:

- Project 400 kV OHL Pancevo (RS) – Resita (RO) has shown significant influence on (n-1) security criteria, in all analyzed regimes
- Project 400 kV OHL Banja Luka (BA) – Lika (HR) has shown less influence on (n-1) security criteria, in all analyzed regimes
- Project 400 kV OHL Bitola (MK) – Elbasan (AL) has shown influence on (n-1) security criteria in Highest Consumption regime
- Project new 400 kV interconnections RS-BA-ME has shown influence on (n-1) security criteria in Lowest Consumption regime

It should be pointed out that Base Case models are more comparable to SECI RTSM initial model, than Alternative Case model, because in Alternative Case models four HVDC links are in operation while in SECI RTSM and Base Case models, only two of them are in operation. Nevertheless, market based models show significant differences in load flow patterns when compared to model based on individual information from each TSO's National Development Plan. Main reasons of such differences are in first place:

- market integration
- different initial assumption of countries balances
- different RES production profile

CONCLUSIONS

Within this USAID/USEA project the most detailed South East European electricity market model has been developed and verified by all regional TSOs. In addition to the previously developed power system model (SECI), this study used the most relevant and detailed inputs for evaluation of large infrastructure investments on the regional network and market development. The study has shown that market based results gave very different generation footprint in the region when compared to predictions of individual TSOs. Main reasons for such differences is in additional market coupling introduced different country balances, different generation schedules than the ones based on individual TSO experience and higher RES penetration per country.

After comprehensive electricity market study resulting wholesale prices are comparable to actual market prices. In SEE wholesale electricity prices are mainly harmonized, which presents practically fully integrated SEE electricity market although network congestions are still present in the region. Average market price in SEE region is increased by 1.60 €/MWh in the Base Case and 3.75 €/MWh in the Alternative Case compared to results of the Reference Case. It can be concluded that additional HVDC links to Italy increase wholesale prices in SEE region for up to 10%.

Total generation in SEE region is increased by 3.35 TWh (0.96%) in the Base Case and 8.98 TWh (2.58%) in the Alternative Case, compared to the Reference Case scenario. In the Base Case net interchange of SEE region is 3,284 GWh higher than in Reference, while in the Alternative Case it is 8,753 GWh higher than in the Reference Case scenario.

Dominant power exchange directions can be perceived through power transfer values and the occurrence of congestions. Total transfer sums up the absolute values of total yearly import and export, and Serbia has the highest total transfer in all scenarios, but transfer decreases in Base and Alternative Case compared to Reference Case. When looking at the power flow in just one direction, generally, in both Base and Alternative Case the highest power transit in SEE region can be expected from Romania and Bulgaria to the neighboring countries.

In terms of cross-border flows, significant congestions can be noticed in both Base and Alternative Case. In the Base Case congestions occur especially on the BG-GR, AL-GR, SI-IT borders and HVDC cable ME-IT, but only in one direction – to Greece and to Italy. Congestions can be also observed on CE-HU and CE-SI borders, in the direction from Central Europe. In Alternative Case total cross-border congestions are even higher than in Base Case scenario, but are more evenly distributed. Congestions mostly occur on CE-SI and CE-HU link in the direction from Central Europe, and on the BG-GR border in the direction to Greece, as in the Base Case. In Alternative Case congestions on RO-RS border can be also observed, in the direction from Romania to Serbia. Occurrence of congestions on these borders is a market signal for increasing cross-border capacity.

Effect of CO_2 emissions prices has also been evaluated. In all scenarios w/o Carbon Cost electricity generation is expectedly increased. In the Base Case total SEE region generation is 14.49 TWh higher and in Alternative Case 14.52 TWh higher than in main set of scenarios that include Carbon Costs. Since these scenarios do not include Carbon Cost, cost of generation is lower and thus market prices in SEE region are lower. Without Carbon Costs average wholesale price in SEE region is 5.60 €/MWh lower in the Base Case and 3.84 €/MWh in Alternative Case than in the main set of scenarios with Carbon Costs.

For the network analyses, it can generally be concluded that market coupling in SEE region introduces changes in existing load flow patterns. Changes in power flows in SEE transmission networks will lead to network overloading in the cases when all network elements are in operation. Under these network topology conditions voltage levels will be within permitted ranges for Highest Consumption and Highest RES penetration regimes. For Lowest Consumption regime network node voltages are out of acceptable limits.

In terms of (n-1) security criteria assessment, Highest RES penetration regime is identified as the most critical one for the Base Case scenario. In this regime, outage of 400 kV OHL Portile de Fier (RO) – Resita (RO) causes overloading of 400 kV OHL Djerdap (RS) – Portile de Fier (RO). For other two regimes, Highest Consumption and Lowest Consumption, transmission networks in SEE region satisfy (n-1) security criteria.

Highest Consumption regime is identified as the most critical one for (n-1) criteria in the Alternative Case scenario. In this regime, outage of 400 kV OHL Konjsko (HR) – Mostar (BA) and outage of 220 kV Konjsko (HR) – Zakucac (KR) are causing overloading of 220 kV OHL Zakucac (HR) – Jablanica (BA)

One of the findings was related to the voltage profiles in the region, in particular for the minimum system loading regime. The whole region is facing this issue for a longer time frame due to significant changes of the load pattern (heavy industry collapsed, larger share of households and services etc.). Therefore, detailed reactive power compensation studies in the region are necessary to resolve this issue on the regional level. It is one of the preconditions for sustainable and operationally safe integration of large network investments analyzed in this study.

BIBLIOGRAPHY

[1] SECI Transmission System Planning Working Group: "Impact of Adriatic submarine HVDC cables to South East European Electricity Market Perspectives", EIHP/EKC (financed by USAID/USEA) 2017

[2] 10-year network development plans of the SEE TSOs (ELES, HOPS, NOS BiH, EMS, MEPSO, KOSTT, OST, Transelectrica, CGES, NEK), 2015-2016

[3] ENTSO-E Pan European Market Modelling Database, 2014

[4] ENTSO-E TYNDP, 2016