Black Sea Regional Transmission Planning Project Optimal Power Flow Modeling

Energy Technology and Governance Program:
Cooperative Agreement: AID-OAA-A-12-00036

January 28, 2014

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Energy Technology and Governance Program

Black Sea Regional Transmission System Planning Project (BSTP)

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Prepared for:

The Black Sea Regulatory Initiative

Cooperative Agreement with USAID: #AID-OAA-A-12-00036

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The development of the Black Sea Regional Transmission Planning Project Optimal Power Flow model in 2012 provides Black Sea transmission system operators with a tool to conduct analysis of the regional network's capacity to support security constrained economic dispatch of the Black electricity generation fleet. Though limited in its ability to perform complex time series analyses, the OPF model provides TSOs, regulators and policy makers with a tool to simulate the benefits of, and requirements for, regional optimization of the Black Sea electrical network. This paper discusses the development of the model, summarizes results of preliminary analyses using the model, and suggests modes of cooperation between Black Sea TSOs and regulators in employing the model to accelerate clean energy development and trade in the region.

Overview of the Black Sea Regional Transmission Planning Project

The Black Sea Regional Transmission System Planning Project (BSTP) was established by the United States Agency for International Development (USAID), the United States Energy Association (USEA) and the transmission system operators of the Black Sea region in 2004 to build institutional capacity to develop and analyze the region's first common transmission planning model. Members of the project working group represent the transmission system operators (TSO) of Armenia, Bulgaria, Georgia, Moldova, Romania, Russia, Ukraine and Turkey.

The Sofia Project Memorandum of Understanding (MOU), signed in 2004, provides the basis for the project organization and coordination, details the Project methodology, timelines, schedules and deliverables, the rights and responsibilities of the TSOs, the role of the Technical Coordinator, the role of Electricity Coordination Center (EKC) as regional model integrator and the support provided by USAID and USEA.

The goals and objectives of the BSTP Project are to:

- Promote regional cooperation on transmission planning among Black Sea TSOs;
- Identify priority investments in transmission systems and interconnections to improve reliability of the regional power system;
- Propose possibilities to enhance electric power trade in the Black Sea Region;
- Harmonize transmission planning principles and methods;
- Create a working group with experts trained in transmission planning issues and well informed about the characteristics of participating power systems
- Develop a common platform (common database, common software and consistent principles) for transmission system analysis among the TSOs in the Black Sea Region;
- Provide training in the use of transmission planning software (PSS/E);
- Promote the results of the analysis to a wide audience of policy and regulatory authorities.

Power System Simulator for Engineers (PSS/E) – the BSTP Planning Platform

The Power System Simulator for Engineers (PSS/E) software was selected as the common planning software platform for the Project. PSS/E was created by Power Technologies, Inc. and is used in more than 150 countries for load flow and dynamic modeling and analysis. Power Technologies, Inc. was acquired by Siemens and today PSS/E is a member of the suite of transmission planning and operations software offered by Siemens. PSS/E contains several modules used by BSTP TSOs for transmission planning purposes, including load flow modeling and analysis, dynamic modeling and analysis, short circuit analysis and Optimal Power Flow analysis.

The Project has supplied each TSO with software, licenses and ongoing training in its use and application of PSS/E to construct national and regional models of the Black Sea high voltage electric

power transmission network. Using the PSS/E software, the BSTP Working Group developed the first detailed national and regional load flow and dynamic models of the high voltage network for the 2010, 2015 and 2020 planning horizons. These models are used to identify bottlenecks to regional trade of electricity; model the impact of the transmission network on energy security initiatives; determine the potential to integrate renewable energy resources; and identify network investment requirements.
Early BSTP studies focused on load flow, security constrained analysis of cross border power exchange in the region. The studies employed a simple method to determine the maximum amount of electricity that could be transferred to/from countries within the region and to countries in neighboring regions. Because most Black Sea countries possess surplus generating capacity early BSTP efforts to simulate regional flows of electricity assumed that all systems were exporters, without accounting for differentiations in the cost of electricity production and transmission in each country.

PSS/E Optimal Power Flow (OPF) Simulates Cost Based Regional Flows of Electricity Trade

To develop more accurate forecasts, the BSTP Working Group elected to model the most probable, economically based electricity trade patterns using an electricity production cost based planning model of the Black Sea regional network. To do so, the BSTP used the Optimal Power Flow (OPF) feature of PSS/E. OPF simulates an economic dispatch of the Black Sea generation fleet based on the cost of production. This model provides the Black Sea TSOs with the first region wide congestion constrained planning model that couples the simulation of economic dispatch of the entire Black Sea generation fleet with a reliability based load flow model of the regional transmission network. Using the model, BSTP TSOs can simulate and analyze the Black Sea network’s capacity to support cost optimized flows of electricity within the region.
To create a regional OPF model, each TSO first created and tested their own national model and made adjustments so that modeling results corresponded to real system behavior. When all national models were tested and approved by the TSOs, a regional OPF model was constructed by integrating the national models into a single regional model. The model was created for planning years 2015 and 2020 for one winter peak and summer peak loading hour. It is used to perform analyses of a single “snapshot” hour of the system.

The OPF regional model has been used in this project to calculate average generation costs in each country and to optimize those costs under various synchronous scenarios. The model consists of two types of data: transmission network data and generation data. The network data describes the network limitations based on the countries grid codes and rules of engagement for power plants. This includes voltage limits and line and transformer load ratings. The generation data of the model deals with all the machines connected to the network. Each generator is modeled individually with an appropriate data set consisting of generation dispatching data, generator reserve data and generation cost curves. For all new generator units and units where data is not available, typical parameters or production unit construction data were used.

The OPF model collects generation cost curves of each modeled power plant in the Black Sea region. These curves define the fuel costs at varying levels of generation output. Since TSOs do not have full access to all the cost curve data, the project developed generic cost curves based on types of plants and its fuel input. The generation cost is represented in four different curves:

1. input/output curve
2. fuel-cost curve
3. heat-rate curve

4. incremental cost curve

In addition to collecting the transmission network and generation data, the project also integrated the forecasted renewable energy capacity being developed in the region into the OPF model. The project published the *Renewable Energy Compendium Report*, which is a compilation of renewable energy generation forecasts for each country in the region. To develop the estimates on a country-by-country basis, each TSO completed a questionnaire on national renewable energy policies, regulations, renewable energy development plans, tariffs and other fiscal incentives for renewable energy, connection procedures and critical issues effecting the integration of intermittent renewable energy resources. In addition to the TSO questionnaires, EKC collected data from Ministry forecasts, and other reports prepared by IFIs and USAID.

The Compendium concludes that BSTP system operators expect to incorporate large quantities of renewable energy in the form of wind, hydroelectric and solar generators in the medium and long-term planning horizons. The addition of this capacity will change the planning and operational parameters of national and regional transmission networks. Data from the *Renewable Energy Compendium Report* was used to populate the 2015 and 2020 OPF and load flow models to provide the most accurate estimates of renewable energy generation capacity available in the region.

OPF Simulation Runs & Results

With the complete OPF model, the project ran different simulations of the regional network model with various generation patterns, different calculation options and synchronous and asynchronous interconnection modes. The first run of the model simulated three scenarios:

1. **Split Mode (two market regions ENTSO-E and IPS/UPS)-** In this simulation run, the interconnection lines between TSOs have no constraints and the system is being optimized only on the differences in average production costs.

2. **Parallel Mode (ENTSO-E and IPS/UPS market regions are coupled**)- For this simulation, once again, the interconnecting lines between TSOs have no imposed constraints, but all interconnection lines are put into operation, so the system is operating in parallel and then optimized by the differences in average production costs.

3. **Parallel Mode Constrained** (**ENTSO-E and IPS/UPS market regions are coupled**)-In this scenario, the simulation assumes that the system is working in parallel, but constraints on interconnection lines between areas have been taken into consideration. The flows on these lines are limited by the net transmission capacity (NTC) values for winter and summer peak hours in 2015 that were calculated by the TSOs using the accepted ENTSO-E methodology.

The results of all three OPF simulation runs were compared to non-optimized simulation runs using the 2015 regional model. By using the OPF model, average costs of production (AVG) and the price of the last unit engaged to cover demand (generation marginal price GMP) for each country have been calculated in a non-optimized way and then compared to OPF optimized calculations to demonstrate the value in fuel cost savings when all generating plants in the region are optimally dispatched. In the first two simulations, when there is no constraint placed on the interconnecting lines between TSOs, the exchanges are based solely on differences in average production costs which are then optimized by OPF.

The current power balances in the regional 2015 model, the “non-optimized” figures, indicate that the all the countries in the region have excess power production capacities for most of the year and most have export capability during winter and summer peak hours. The results of the OPF analysis are presented showing the average system electricity cost (AVG), the price of the last unit engaged to cover demand (generation marginal price GMP), the transmission tariff for each TSO and the amount of available export (+) or required import (-) for each TSO. All calculations are based on 2015 winter and summer peak hours. The values for the Tariffs represent wholesale prices in the fourth quarter of 2011 on high voltage transmission lines. For systems where a market based approach is implemented, the tariff represents the wholesale market average price for electricity; for all others the tariff represents the average wholesale tariff.

The following are results for the average electricity cost savings for each simulated scenario:

1. **Split Mode-** for the ENTSO-E region, the average production cost is reduced by 1.37 %, equivalent of $48,610 per hour for summer peak, and 1.38% ($52,610) for the winter peak. For IPS/UPS, the savings total to $43,380 per hour, a 1.85% reduction during the summer peak and 3.5% ($98,060 per hour) for the winter peak.

2. **Parallel Mode-** the results for the winter peak indicate there is a savings of 1.7% ($112,000 per hour. For the summer peak, the savings equal to 1.01% ($58,900 per hour).

3. **Parallel Mode Constrained-** The summer peak savings total to .02% ($13,800 per hour), while the savings for the winter peak are much greater reaching 1% ($54,200 per hour).

When optimization replaces high cost production with lower cost production in an unconstrained manner, the savings can be substantial. For example, when the IPS/UPS was optimized in the winter Split Mode, the average production costs were reduced by 3.5 %, a savings of $98,060/hour for the IPS/UPS region. When the entire BSTP region was optimized in the winter Parallel Mode, the savings were $112,000 per hour (1.7%) for the region. If increased trading as a result of the optimization process was only 2,000 hours per year, savings in the region could amount to $200 million per year.

In terms of export and import calculations in the parallel constrained scenario, the results of the OPF optimization demonstrates that exports from Romania and Bulgaria are significantly decreased while exports from Russia, Georgia and Azerbaijan are increased. When exports in Romania and Bulgaria are reduced, their average production costs are significantly increased; from $67.1/ MWh to $70.9/ MWh in Romania and from $60.1/ MWh to $63.0/ MWh in Bulgaria. These increases are due to the must run requirement of higher cost wind power plants and CHP plants (in winter regime) that exist in these two countries.

OPF Model Sensitivity Analysis

Throughout the OPF model development, assumptions made on the input data impact the results of the study. Global and local factors can strongly influence production cost variation, power system exchanges and investment in interconnection lines in the Black Sea Region. To account for these elements and further the analysis of the initial results from the OPF model run, the Project is conducting a sensitivity analysis on the influence of the following key parameters:

- **Fuel Costs-** taking into account global price forecast variations defined by the global fuel market
- **Carbon Costs**- defined by penalty factors for greenhouse gas emissions. This can impact thermal power plants, depending on the fuel type, and can imply different production costs and possible power exchanges
- **Rates of Capital Depreciation**- power plants will be examined in two scenarios: fully depreciated without any capital cost and as newly built with full capital costs.
- **Hydrology** –wet and dry regimes will be analyzed during specific load levels (winter peak, summer and summer off-peak)
- **RES integration**- high and low RES penetration will be analyzed during specific load levels (winter peak, summer and summer off-peak)
- **Interconnections**- a predefined list of new interconnecting lines will be analyzed. Construction of new interconnecting AC or DC network elements could increase optimized usage of production capacities and trading levels between countries
- **NTC variations** – analysis of the impact of the transmission network developments in the Black Sea region on NTC values. The list of lines will be specified by the participating TSOs and their regulators. TSOs will also report on overloaded critical grid elements and the related tripping events with references to the analyzed winter and summer peak regimes

The overall analysis will provide an overview of how the different factors influence the power system production costs and possible power system exchanges. The region will be analyzed as a coupled market and the analyses will be performed for the 2015 models. The scenarios for this analysis will be determined based on the collected data, agreed synchronous scenarios, wind engagement according to the TSOs estimation and engagement of power plants derived from OPF analysis. When the variables with the largest impact on study results are identified, more research can be conducted to fine-tune these inputs and ultimately increase the reliability of the results.

In June 2013, the BSTP project conducted a partial sensitivity analysis that analyzed the impact of variations of capital cost, CO2 emissions and fuel costs. The initial results concluded the following:

Capital cost variation Winter peak scenario

- In a scenario without capital costs attached to generator bids, the average cost of production decreases across the region
- In scenario without capital costs, the greatest impact on countries net exchanges occur on the Russian – Ukrainian border, where the export from Russia to Ukraine decreases. This due to the more competitive position of the new Ukrainian coal plants on the market and their short run generator biding marginal costs.

CO2 emission cost variation Winter peak scenario

- Variation in CO2 emission costs has the greatest impact on the production cost of coal plants.
- In a high CO2 emission cost scenario (50$/tCO2), the greatest effect is on Moldova, with an increase of 69% in average production costs followed by Ukraine and Bulgaria with increase of 34% in average production cost.
- The least affected country is Georgia, due to the power production from hydro power plants.
- The net exchanges between the countries stay relatively constant. There is a notable decrease in exports from Bulgaria and an increase of imports in Ukraine. This is primarily due to heavy penalties on coal plants for emissions.

<u>Fuel cost variation Winter peak Scenario</u>

- Fuel price variation has a large influence on power systems with dominant thermal production like Turkey, Azerbaijan and Armenia
- The Georgian average cost of production is least impacted by fuel price variations due to its predominant hydro power resources.
- In a high fuel cost scenario, the Ukrainian imports of electricity decrease due to assumed larger increase in gas prices than coal, making the coal plants in Ukraine more competitive.
- In a low fuel cost scenario, Azerbaijan exports increase on the account of Georgia's exports. Decreased gas prices create a more competitive position in the market for plants in Azerbaijan.

The remaining sensitivities are scheduled to be analyzed over the summer of 2013. Results will be presented and discussed at the next BSTP meeting to be conducted in October 2013.

<u>Sub-Regional Application of the OPF: Romania-Ukraine-Moldova Interconnection</u>

In addition the BSTP project, the OPF model was applied in the Romania – Ukraine – Moldova Sub-Regional Transmission Planning Project (RUM). The RUM project is focused on investigating options for the restoration of the 750 kV transmission corridor between Isseaca in Romani, Iujno Ukrainska in Crimea, Ukraine and Varna, Bulgaria. The line was constructed in 1986 and went out of service in the mid-1990s. Restoration of the line holds the potential to improve energy supply for Moldova, provide it with a seasonal export route for electricity sales to the Energy Community and provide a second export route for electricity sales from Ukraine to Southeast Europe. The objective of the project is to analyze the high voltage networks in each of the countries from a sub-regional perspective and recommend the final disposition of the 750 kV Issaccea – Iujno Ukainska line.

Using the OPF model, the RUM project conducted an analysis with different scenarios to identify the optimal transmission configuration for the new corridor. The project developed a cost benefit analysis using the results from the OPF model. This provides TSOs with an indication of the savings for each scenario from the optimum power exchanges. The cost benefit analysis compared the OPF results with the investment cost and operation and maintenance costs of the candidate investments through the RUM corridor.

<u>Conclusions: TSO/Regulatory Cooperation on Modeling and Analysis</u>

The addition of the OPF model to the suite of BSTP planning tools gives regional planners a platform to couple economic and efficiency parameters to reliability criteria for the first time. As such, it is following the path of regional planning efforts in North America and Europe, which have incorporated market based economic dispatch in their planning models as their electricity markets matured over time. To move forward with this kind of analysis, the BSTP project will require more sophisticated software to simulate markets. OPF is limited because it can only estimate costs for one hour. It provides a single snapshot of the system and not a time series for market analysis.

The initial joint meetings of the Black Sea Regulatory Initiative (BSRI) and the BSTP project have provided the participants with opportunities to better understand their respective technical and regulatory priorities and forge synergies needed to accelerate regional trade and exchange of clean energy. Through this collaboration, the TSOs and the regulators have the opportunity to discuss issues of regional importance to clean energy trade and development. Members of the BSRI can collaborate with BSTP counterparts by recommending policy and regulatory-driven scenarios to be analyzed in future studies that would allow the TSOs to fine tune their models and a conduct sensitivity analysis based on newly provided data. Inputs can include:

- Trade scenarios between countries
- Fuel price variations
- Carbon prices
- New interconnections
- Renewable integration

With further collaboration, the following studies can be conducted jointly by the Working Groups using the OPF model:

- Joint investigation of projects of regional significance to clean energy development and trade
- Use of the model to evaluate the maximum potential to integrate clean energy sources of electricity generation
- Investigations of scenarios based on national energy strategies
- Calculation of cross border net transfer capacity (NTC)

It is proposed that the BSTP and BSRI Projects organize a small committee consisting of TSO and regulatory experts to accelerate cooperation between the two projects. The TSO members of this committee could work with the regulators to review their work products, providing input to terms of reference and guidance on findings from a technical perspective. They will also seek input from the regulators on the development of scenarios for further analysis by the BSTP.