Cost Benefit Analysis of Transmission Grid Expansion in the Central and Eastern Continental Europe Electricity Market

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***Abstract*— The distinctions of the wholesale electricity price of different European regions results on the one hand of the different power plant portfolios and on the other hand from limited transmission capacities between the countries. The increase of side specific RES-E generation technologies can lead to an intensification of the price differences. To counteract these price distinctions, the European Network of Transmission System Operators for Electricity (ENTSO-E) committee has published a lot of documents where the importance of transmission grid expansion is accounted in detail. Based on a market coupling algorithm an n-point model, in which each point represents a defined market area, will be presented. This algorithm will be implemented in MATLAB and delivers the economic influence of the expanded transmission grid between the market zones. The cost benefit analyses furthermore allows a detail discussion of benefits, like the increase of the social welfare, fossil fuel savings and CO2-emission reduction.**

***Index Terms*— Cost Benefit Analysis, Market Coupling, Net Export Curves, Transmission Grid Expansion**

I. INTRODUCTION

The European electricity markets are characterised by significant wholesale price differences. The main reasons for these price discrepancies are on the one hand the different electricity production costs between areas which have cheaper power plants and those which are more expensive, and on the other hand the limited transmission capacities between the regions [1]. The future increase of side-specific RES-E generation capacities, which are not necessarily located nearby the load centers, will increase the electricity price differences in Europe if there will be no significant transmission grid extensions. The future increase of large wind parks (e.g. in the north of Germany) or large PV-farms (e.g. in the south of Europe) can lead to cheap prices in the region if the RES-E generation is high (e.g. a windy day or a high PV supply) and the transmission lines are high congested. In the coming decade, the net generation capacity will increase by about 250 GW in Europe, i.e. 26% of the present total and almost all can be explained by RES development [2]. The major shift in the generation mix will induce a massive relocation of the generation, with large wind farms and solar capacities. This significant increase of high volatile generation capacities requires the adaptation of the transmission grid. Beside the price differences and the future increase of side-specific RES-E generation capacities, security of supply reasons and the required increase of the European market integration are the main reasons for transmission grid extension. ENTSO-E has identified 112 projects of pan-European significance in the ten-year network development plan 2012 (TYNDP) with specified total investment costs of €104 billion, which furthermore highlights the importance of grid extension.

This paper develops a cost-benefit analysis of future cross-border transmission capacity extension between different countries in central and eastern continental Europe which will be implemented in a MATLAB-market-model. The evaluation of the economics of the transmission grid extension consists on the one hand of the calculation of the social welfare (incl. producer- and consumer surplus) in each market and on the other hand of the calculation of the congestion rent between the markets. These two parameters will be used as a benchmark for the investment of the transmission grid extension (HVDC - high voltage direct current and HVAC - high voltage alternating current) between the markets. Beside these parameters the method allows a detailed discussion of other benefits, like fossil fuel savings and CO2-emission reduction.

Within this paper the preliminary stage of the meshed n-point model, a 3-point model including Austria, Germany and Italy is presented. The electricity market of Italy is characterised by higher market clearing prices compared to Austria and Germany [3]. Whereas the price levels of Germany and Austria are almost at the same level. The main reason for this price convergence lies in the fact that no significant congestion exist between the Austrian and German electricity market [4]. The transmission lines between Austria and Italy are significantly congested which is among other reasons responsible for the price differences. Therefore the economics analysis of a possible transmission extension between Austria and Italy is the main part of the analysis.

The analyses focus on the economics of the transmission grid between the markets. The analyses do not take into account the power flows due to national market exchanges, which may result in a reduction of power system security. The following method which is implemented in MATLAB is based on net export curves (NECs) [5]. The NECs are created by the hourly based merit order of each target country and its hourly based

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demand and are needed to calculate the changes in the social welfare and the congestion rent.

A. *Market Coupling*

1) *NEC definition*

The net export curve (NEC) is defined as difference between local supplier and consumer bidding curves and represents the availability of import/export of electrical energy of a market zone [1], [5]. The market clearing price is equivalent to the NECs intersection with the ordinate axis. The stepwise NEC is generated graphically by shifting the demand curve horizontally over the supply, as shown in fig. 1. Each intersection between supply and the shifted demand represents the NECs price level on the shifted volume. If the local supply cannot meet the local demand, because of not enough existing generation capacity the NEC only exists in the left half plane and the intersection with the ordinate will set to the price level of the demand. The total load is assumed inelastic with a price cap of 150 €/MWh.

The left picture in fig. 1 illustrates an exemplary merit order, its demand and the resulting market clearing price p of a local electricity market without import and export. The solid black line in the right picture illustrates the NEC of this market. The qualitative progression of the NEC relates beside the supply function also to the demand function in the market zone. If demand intersects the supply in a discontinues point, always the higher price level of the merit order will be used for the NEC construction. As a result, the volume of a price level can be different between the merit order and the NEC (e.g. $\Delta q1 \neq \Delta q2$), as shown in fig. 1. By reflecting the NEC with respect to the ordinate the NEC become the net import curve (NEC').

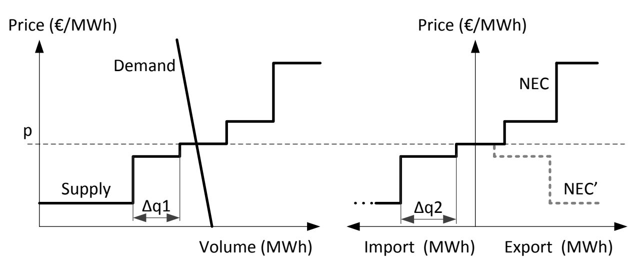

Fig. 1: NEC Definition according to [5]

Both, the NEC and NEC' will be created with the MATLAB-model and are used for calculating the social welfare and the congestion rent which are benchmarks for the economic analyses of future transmission grid extension.

2) *Bilateral Market Coupling*

Market coupling is a mechanism for matching orders on the exchange and it is an implicit cross-border allocation mechanism, which simplifies to cross-border trade between electricity markets [5], [6]. Market coupling improves the economic surplus of the coupled markets.

Under consideration of two neighboring markets (market A and market B) with different market clearing prices (p_A and p_B) at a certain point of time and under assumption that the market clearing price of market A is higher than the market clearing price in market B, the market coupling mechanism works as follows: The local market with the lower market clearing price (market B) is the exporting market whereas market A acts as importing market. The NECs of the markets are illustrated in fig. 2. The available transfer capacity (ATC), which is defined as difference of the net transfer capacity (NTC) and the already allocated transfer capacity (AAC)

$$ATC = NTC - AAC \tag{1}$$

between the markets is the responsible parameter which determines if price convergence occurs or not. If the ATC is congested and equal to ATC_1 in fig. 2, the price levels of the markets remain at the same value ($p_{A1'} = p_A$ and $p_{B1'} = p_B$). The area between the NECs is split into the congestion rent (CR) and the congestion losses (CL). CR is a measure of the amount collected by the owner of the transmission rights whereas the CL represents the re-dispatch costs and reflect the additional costs for electricity generation in the constraint local area to balance local supply and demand [7], [8]. The social welfare of the two markets will stay at the same level because the price levels of the market remain unchanged.

If the ATC is not congested and equal to ATC_2, price convergence will occur ($p_{A2'} = p_{B2'}$). The CR and the CL are zero because the transmission line is not congested. The whole area between the NECs in fig.2 represents the change of the social welfare.

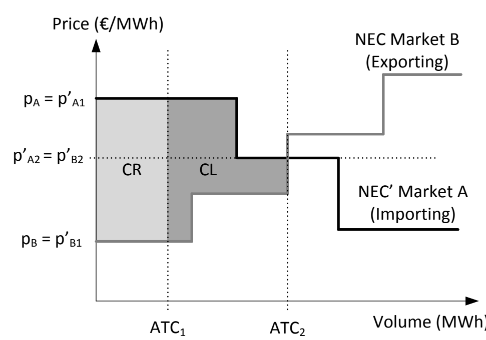

Fig. 2: Market Coupling with Net Export Curves according to [7]

The change of the social welfare for the case that the ATC is high enough to reach price convergence between the markets is illustrated in fig. 3. The left part of the figure represents the exporting electricity market. The demand rises in this market because of the additional demand from abroad. The market clearing price rises from p_B to p_B'. The areas A and B represent the change of consumer surplus (CS), producer surplus (PS) and social welfare (WF). The complete calculation is shown within fig. 3. The consumer surplus decreases market B because the price level rises to a higher level. The change of the producer surplus behaves contrary. All in all the social welfare rises to a higher level by area B.

The right picture in figure 3 illustrates the importing electricity market. The surplus of the supply of market B is imported in market A. The new supply bidding curve of market A results by sorting the local merit order and the surplus of market B in ascending manner. The resulting supply bidding curve includes parts of the previous merit order (illustrated black in fig.3) and parts of the surplus of market A (illustrated grey in fig.3). The new intersection between the merit order and the demand results in a lower market clearing price (p_A') and in an increase/decrease of the consumer-/producer surplus. The areas C and D and the formulas under the right picture in fig. 3 depict the changes in the social welfare in detail.

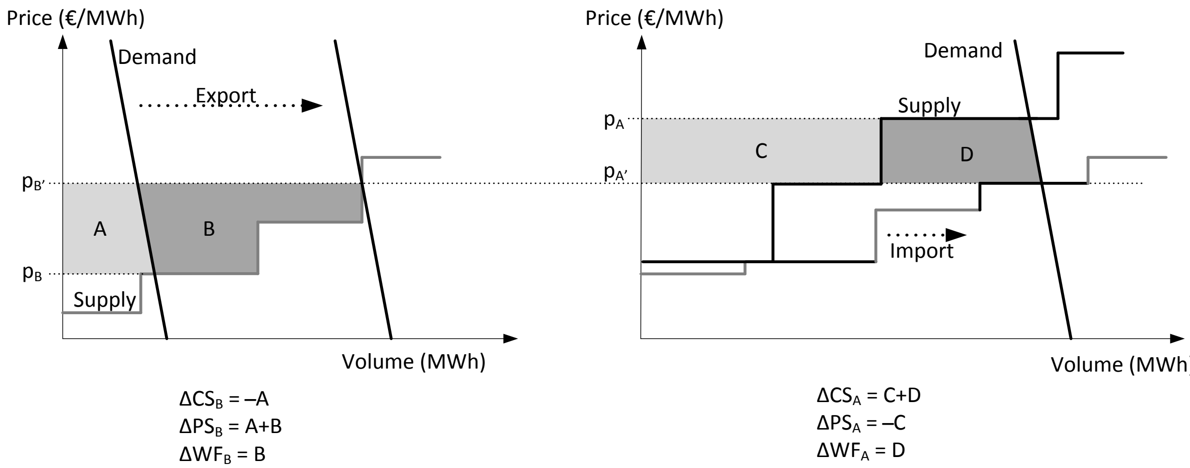

Fig. 3: Market Coupling – Calculation of the Social Welfare

Fig. 3 furthermore shows that changes of the WF require changes in the price level of the markets.

3) Trilateral Market Coupling

The complexity rises by analysing three different markets. Fig. 4 shows the simplified flow chart for the case of three local markets. First of all the bilateral market coupling algorithm is used to couple the two neighboring markets with the cheapest market clearing price. Two possible results can occur. If the limited ATC avoid price convergence between the markets, which means the transmission line is fully used; only bilateral market coupling between the remaining markets is possible. If price convergence occurs a common NEC will be created to couple the combined market with the remaining market. Again, if the remaining ATC between the three markets is high enough, price convergence of all three markets will be reached. In the other case the already coupled markets stay coupled and as a result the third market will have a higher price level.

The combined NEC of two electricity markets is generated by the supply and demand curves of both markets. Every part of the combined NEC must be related to the origin market in order to allocate the cross-border exchange to the correct transmission line.

This presented market coupling algorithm according to [5] and [7] is used to calculate the revenues of the transmission grid expansion and to illustrate the changes in the social welfare. The resulting market prices, the remaining ATC, the changes in the social welfare, the congestion rent and the congestion losses are outputs of the MATLAB-market-model.

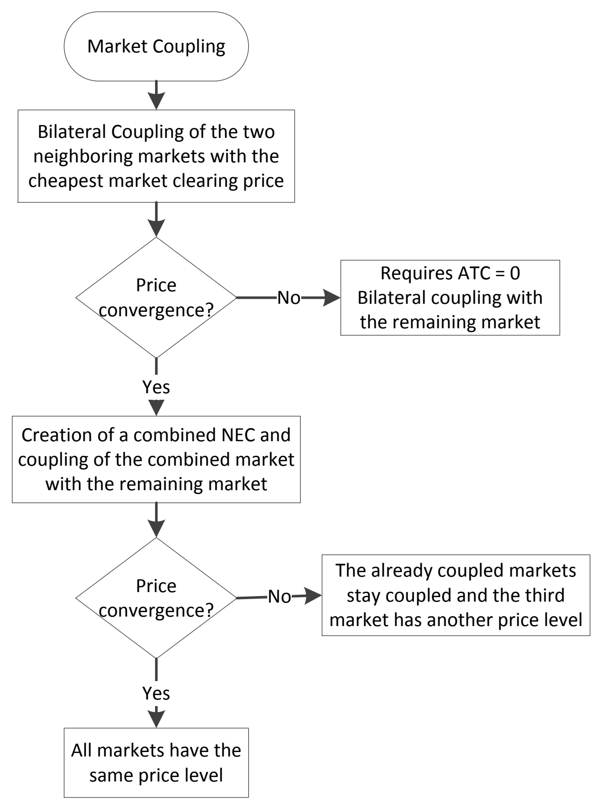

Fig. 4: Simplified Flow Chart of the Market Coupling Algorithm

In the following the preliminary stage of the model, a 3-point model between Austria, Germany and Italy is analysed and discussed in detail.

4) *Supply and demand of the three electricity markets*

The market coupling algorithm is based on the hourly merit order and the hourly based local demand of the electricity markets Austria, Germany and Italy.

a) *Demand*

The hourly based electricity demand is removed from ENTSO-E [9] for the year 2011. Additionally an increase of the demand of 2% per year is assumed to create demand scenarios for 2020 and 2030.

b) *Supply*

The installed capacities of the different generation technologies for the three different countries are removed from the PLATTS database [10], with the exception of wind and photovoltaic (PV). The sources of these two RES-E generation capacities are the Scenario Outlook and Adequacy Forecast 2012 (SOAF) [11] published from ENTSO-E. The installed capacities are multiplied with a capacity factor for each generation technology. The price level of each generation technology is fixed to a certain level and the amount of supply for each generation technology is assumed as constant over the year, except PV, wind and run-of-river. The feed-in profile of PV, wind and run of river power plants are extracted from APG for Austria, the four TSOs of Germany for Germany and from Terna for Italy for the year 2011.

For the scenarios 2020 and 2030 no further power plant extensions is assumed, expect PV and wind. The increases of these two RES-E generation technologies are removed from the latest SOAF 2012 [11].

5) *Transmission Expansion between the markets*

The current status of the NTC between the analysed markets according to ENTSO-E [12] is assumed as follows:

TABLE I
VALUES OF THE NTC ACCORDING TO ENTSO-E

Net Transfer Capacity in MW			
from / to	***Germany***	***Austria***	***Italy***
Germany	-	2000	-
Austria	2200	-	285
Italy	-	220	-

The Ten-Year Network Development Plan (TYNDP) [2] from ENTSO-E provides the information of future planned transmission grid extensions. Especially the project number 26 and 47 are relating to the analysed countries. This paper analyses on the one hand the economics of a 750MW high voltage alternating current (HVAC) line between Austria and Italy till 2020 and on the other hand a 2 GW high voltage direct current line (HVDC) between Austria and Italy via “Brenner-Tunnel” till 2030. The transmission grid for the scenarios 2020 and 2030 between Germany and Austria is assumed to stay at the same level as 2012.

II. RESULTS

First of all, under consideration of the three local markets, without net cross-border exchange between the countries, the result of the market-model for the year 2011 clearly shows that the market clearing price of the German electricity market is less than the Austrian or Italian during the winter months, whereas the local market of Austria cannot cover its own demand in a few hours. As a result the cross-border flow is directed from north to south. The Austrian electricity market imports electrical energy from Germany, which results generally in a price convergence between these two markets and in a significant increase of the social welfare. The Austrian electricity price is affected by German imports, which results in a high increase of the Austrian CS and in a high decrease of the PS. The situation in the German market behaves in an opposite way. The congestion rent between these two countries reaches an extremely small value, because the transmission line between these two countries is generally not congested. The price level of the Italian electricity market stays almost all hours at the same level after the cross-border exchange with Austria because the transmission line (table I) is nearly ever fully congested. Therefore the changes in the social welfare are very low compared to the other markets, whereas the congestion rent reaches a high level.

Because of the increase of electricity generation of run-of-river power plants in Austria during the summer months the market clearing price in Austria is most of the time lower than the German market clearing price which results in a reverse of the power flows and in an alternation in the sign of the changes of the CS and PS between Austria and Germany compared to the winter months. The transmission line between Austria and Germany is generally not congested which results again in a small level of the congestion rent. The Italian electricity market is characterised by imports from Austria also during the summer months. The high degree of congested transmission line and the significant price differences show again a high congestion rent. The detailed values for the changes of the social welfare, the congestion rent and the congestion losses with cross-border exchanges for the months January and July 2011 are shown in tab. II.

TABLE II
RESULTS FOR JANUARY AND JULY 2011

Changes in the social welfare and the congestion rent 2011 in Million €			
		January 2011	***July 2011***
Austria	ΔCS	224.4	-85.5
	ΔPS	-198.8	99.6
	ΔWF	25.7	14.1
Germany	ΔCS	-204.1	31.5
	ΔPS	206.2	-31.2
	ΔWF	2.2	0.4
Italy	ΔCS	11.5	29.5
	ΔPS	-11.3	-25.9
	ΔWF	0.2	3.6
CR Austria - Italy		9.1	18.7
CR Germany - Austria		1.0	1.9
CL Austria – Italy		97.4	10.8
CL Germany - Austria		302.3	45.2

The scenario 2020 shows a significant increase of the congestion rent between Austria and Italy, which is a result of the transmission grid extension between these countries from 220 MW to 970 MW (tab. III). The German nuclear face out decision has the consequence that the German market has to import electrical energy form Austria resulting in significant changes in the consumer and producer surplus. The transmission line between Austria and Germany, which stays at the same level compared to 2011, is generally not congested, the price level of Austria and Germany reaches convergence in most cases. The significant increase/decrease of the Italian consumer/producer surplus is a result of the transmission extension but the electricity price in Italy stays on a higher level compared to the other Austrian and German market which results in the increase of the congestion rent (ΔCR_{2020} - ΔCR_{2011}=121 Mio€/year).

ENTSO-E [2] estimates the total costs of the transmission extension (750MW) between Austria and Italy (project number 26 in the TYNDP) higher than 1000 Mio€. To evaluate the concrete price of the transmission extension, further research has to be done, but if project number 26 will be completed till 2020, the preliminary results of the scenario shows that the investor will receive revenues of 121Mio€ per year.

The results of the scenario 2030 show a slightly decrease of the congestion rent between Austria and Italy compared to the scenario 2020 (tab. III). The reason for this decrease lies in the increasing hours of price convergence between Austria and Italy, which are caused by the transmission grid extension from 220 MW to 2200 MW. The increase of price convergence is reflected by the increase of the social welfare in the Italian electricity market.

The congestion rent (ΔCR_{2030} - ΔCR_{2011}) of 63.3 Mio€ per year have to be faced with the transmission grid extension cost of the HVDC line ("Brenner-Tunnel"). De Jong [13] presented a method for the calculation of the HVDC costs but to get the exact value further research has to be done.

TABLE III
RESULTS FOR THE SCENARIOS 2011, 2020 AND 2030

Changes in the social welfare and congestion rent 2011, 2020 and 2030 in Million €				
		2011	***2020***	***2030***
Austria	ΔCS	817.9	-71.2	-1116.3
	ΔPS	-583.7	287.4	1440.5
	ΔWF	234.2	216.2	324.2
Germany	ΔCS	-1015.7	717.7	114.1
	ΔPS	1030.5	-682.4	-83.9
	ΔWF	14.9	35.3	30.2
Italy	ΔCS	241.9	958.2	1088.6
	ΔPS	-219.3	-929.3	-1051.2
	ΔWF	22.6	28.9	37.5
CR Austria - Italy		162.5	283.5	225.8
CR Germany - Austria		18.1	42.4	56.5
CL Austria – Italy		2440.8	902.2	285.2
CL Germany - Austria		241.4	111.4	54.3

III. *CONCLUSION* AND OUTLOOK

The transmission line between Austria and Germany shows no significant congestion for all scenarios. Congestion between Austria and Germany only occurs if the transmission line between Austria and Italy is significantly increased and Italy imports a lot of electrical energy because of its higher price level. Therefore Austria operates as a transit country and the line which is physically between Germany and Austria is used to supply Italy via Austria.

The transmission line between Austria and Italy is significantly congested for the scenario 2011 and 2020. Because of the higher price level of the Italian electricity market, Italy has the tendency to import electrical energy from the neighboring countries. The transmission line between Austria and Italy (220 MW, 970 MW) represents a bottleneck and the price levels stay different in most hours. The transmission extensions show that the congestion losses decrease significantly and reaches 285.2 Mio€ in the scenario 2030 (tab. III).

The preliminary stage of the market-model clearly shows that the increase of the transmission grid between Austria and Italy will lead to benefits which are identified beside others as social welfare and congestion rent. Especially the congestion rent represents an important parameter for the economics of transmission grid extension for private investors.

In the preliminary stage of the model the operation of pumped hydro storage (PHS) are only considered at national level. But the significant increase of the side-specific RES-E generation technologies influences the operation of PHS in the whole system. Therefore an optimasation of the whole system will be done in the next step.

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