

# Inter-TSO Compensation Mechanism

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## Abstract

In the framework of the EU cross-border trade of electricity, international transactions may be carried by several network operators in different Member States. Operators hosting such transits incur additional costs on their local network. The European Commission has issued a proposal, regarding the Guidelines on an Inter-TSO Compensation Mechanism. We show that this mechanism may lead to nonsensical results.

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# 1 Introduction

The EU Regulation on conditions for access to the network for cross-border exchanges in electricity [1], aiming at the creation of a real internal electricity market, establishes principles for setting fair rules for cross-border exchanges in electricity. In particular, this involves the establishment of a compensation mechanism, according to which transmission system operators (TSO) should receive a compensation for any cross-border flow that would imply an additional cost on their horizontal network. This paper focuses especially on the definition and implementation of this compensation mechanism.

Article 3(1) of the Regulation states that “Transmission system operators shall receive compensation for costs incurred as a result of hosting cross-border flows of electricity on their network”. Article 3(2) specifies “the compensation shall be paid by the operators of national transmission systems from which these cross-border flows originate, and systems where those flows end”. The actual magnitude of cross-border flows hosted by a transmission system, as well as the magnitude of cross-border flows originating and/or ending in national transmission systems, should be determined based on measures of actual physical flows (Article 3(5)). Finally, the Regulation gives indications that the cost of hosting cross-border flows (and hence the compensation thereof) should be based on the forward looking long-run average incremental costs (Article 3(6)).

The Regulation only sets general requirements, leaving the practical implementation to subsequent negotiation. By the end of 2004, the Directorate-General for Energy and Transport of the European Commission has issued some Guidelines [2] on the implementation of this specific part of the Regulation. The guidelines are presented in section 2. They have been commented by the Regulators [4] and the Transmission System Operators [5]. They should be operational by the end of 2005.

Article 3 of the Regulation poses a very difficult problem of economic

externality. Because of loop flows, electricity transactions create flows in networks that are not part to the transaction. These flows induce costs that need to be compensated. This is the objective of the Inter-TSO Compensation Mechanism. The problem is that the technology of electric grids makes that externality question unusually difficult. At the same time, European authorities want a simple solution. This paper suggests that the current proposals will not achieve this double objective.

In section 3, we build up a simple example of interconnected network, with four transmission systems, symbolising the North-Western continental European transmission network. In this stylised example, we neglect the effect of flows originating or ending in systems outside of our simplified network. We insist however, that this example is used precisely to help understanding how the compensation mechanism is to be applied and, to some extent, the resulting financial compensations from some TSOs to others. We show how the strict application of the guidelines may in some cases lead to extremely puzzling results, if any result at all. Finally, we present our conclusions in section 4.

## 2 The Commission's Guidelines

### 2.1 Notation

We try in the following to stick as closely as possible to the Commission's notation in the Guidelines. Let  $i$  denote the network transmission operators involved in the cross-border trade (the guidelines also refers to them as *entities*). Before being able to compute compensations, one needs to measure the actual transit flows in a given period (annual in the guidelines – we here depart from the guidelines by keeping a more general formulation by considering a horizon of  $N$  hours).

We denote with  $X_i(t)$  and  $M_i(t)$  the measured flow on interconnections,

respectively in export direction and import direction, during hour  $t$ . The guidelines are not very strict on their definition of these measured flows on interconnections, but we understand that  $X_i(t)$  expresses the sum of all flows on the subset of available interconnections, which are used in the export direction, while  $M_i(t)$  denotes a similar sum, but this time on the subset of interconnections used in import direction (mutually exclusive of the previous subset, at time  $t$ ).

Let  $L_i(t)$  and  $G_i(t)$  respectively denote the total load and total generation in system  $i$  during hour  $t$ . Load and generation will be used to provide an estimate of the local flow on transmission system  $i$ . This quantity will be used, compared with the transit, to determine the part of network costs which are due to transit and must be compensated for.

## 2.2 Determination of Due Compensation

The transit flow hosted by system  $i$  during hour  $t$  shall be defined by

$$T_i(t) = \min(X_i(t), M_i(t)). \quad (1)$$

The amount of compensation to be paid for hosting transit will be in proportion of the ratio of transit flows to total flows on the local network, that is:

$$\xi_i = \frac{1}{N} \sum_{t=1}^N \left( \frac{T_i(t)}{T_i(t) + \max(L_i(t), G_i(t))} \right) \quad (2)$$

The fraction in the sum expresses the proportion of transit to total actual flow on the local transmission system. Variable  $\xi_i$  gives an average of this fraction over the relevant period for transmission system  $i$ .

The first component of the amount of compensation is given by:

$$c_i = \xi_i \times LRAIC_i, \quad (3)$$

where LRAIC denotes the long-run average incremental cost, and will be discussed below.

The second component of the amount of compensation depends on the network losses. It is denoted with  $l_i$  and is proportional to the “total annual losses recorded in the horizontal network, multiplied by market-based average yearly price for energy”. We neglect losses in this paper, but remember that the full compensation mechanism computes the amount to be received by each participant as:

$$r_i = c_i + l_i. \quad (4)$$

In the current mechanism, this compensation should be reduced by an amount  $x_i$ , equivalent to the total import from neighbouring transmission systems from non-participating countries. Indeed, TSOs who declare imports from non-participating countries will contribute 1 €/MWh to the fund. The actual *compensation* received by each Member State should therefore be equal to  $r_i - x_i$ . The total money which needs to be raised to constitute the *Compensation Fund* is therefore given by

$$CF = \sum_i (r_i - x_i) \quad (5)$$

### 2.3 Determination of Horizontal Network and Cost

The horizontal network is the “part of the transmission system, which is used to transmit electricity between countries and within the country: it contains the transmission system elements that are influenced significantly by cross-border exchanges”.

The European Commission provides a more technical and quantitative definition of this horizontal network, but we let the interested reader refer to [2] for further detail. We briefly mention here that, roughly, the horizontal network should be composed of all lines and substations of 220 kV and more.

Each TSO is supposed to submit an assessment of the annual revenue required to cover forward-looking long-run average incremental cost (LRAIC) of its horizontal network. This LRAIC should include capital costs relating to

future investments, corresponding to a renewal of all existing physical assets over a period of 40 years.

## 2.4 Determination of Payments of Compensation

Member States shall contribute to the compensation in relation with their Cumulated Absolute Net Flow (CANF) during the relevant period, according to the formula:

$$CANF_i = \sum_{t=1}^N |X_i(t) - M_i(t)|, \quad (6)$$

which implies that Member States which are large net importers or net exporters (or even large importers during some subperiod and large exporters during other periods) will greatly contribute to the compensation mechanism.

The total compensation fund is supposed to be supported by contribution from Member States, each contributing on the basis of its own cumulated absolute net flow. Therefore the compensation, denoted  $K_i$ , to be paid by each Member State will be determined by formula:

$$K_i = \frac{CANF_i}{\sum_j CANF_j} \times CF. \quad (7)$$

One may easily verify that the total amount paid by all Member States covers the needs for compensation of transmission systems hosting transits.

### 3 A Simple Example

To illustrate the functioning of the above-described compensation mechanism, we present the following simple example. Consider a subset of European transmission operators, composed of German, French, Dutch and Belgian system operators. These transmission systems and their interconnections are sketched on figure 1.

Regional transmission systems are represented by boxes, with only the country's symbol (and more or less proportional to the respective size of each of these markets), regardless of what happens inside. Interconnections between these countries are represented by arrows. Noticeably, and although there is a common border between these two countries, there is no interconnection between Belgium and Germany.

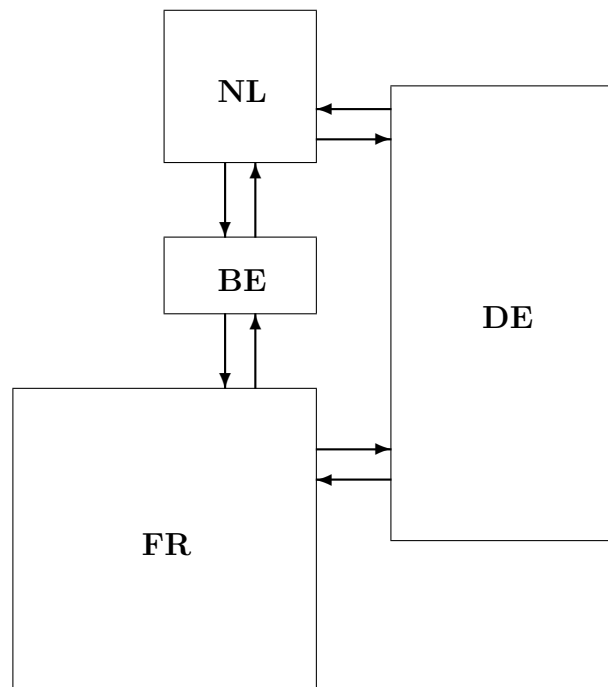


Figure 1: North-Western Europe continental network

In this example, we proceed with three simplifications. First, we reduce the relevant time segment to one single hour, that is,  $N = 1$ . Second, we neglect losses in this simplified network. By doing so, we force the value of  $l_i = 0$ . Finally, we also isolate these four Member States from the rest of the world and suppose they only exchange between themselves, not with the rest of the TSOs.

This simplified case should help us understand how the compensation mechanism functions.

### 3.1 Loop flows

In order to properly measure the physical flows that result from cross-border trade between these four countries, one needs to account for *loop flows*. These result from physics laws, called Kirchoff's laws, which uniquely derive the flow along each line of the network, as a function of the amounts injected and/or withdrawn at each network node, and of transmission network topology. Since electricity must follow these rules, it results that one MWh of electricity generated in France, for consumption in the Netherlands, will not follow a simple and straightforward South-North path across Belgium. Actually, most of this energy will flow through Belgium (probably 70 to 80 percent) but part of it would also flow through the German transmission system, creating a *loop flow* on the French-German and German-Dutch interconnections.

Similarly, one MWh of electricity generated in Germany for consumption in Belgium would partly flow through France, and partly through the Netherlands. If this happened simultaneously to the French-Dutch cross-border trade described above, flows would tend to compensate each other on the Belgian-Dutch and French-German interconnections, but would add up on the two remaining interconnections.

## 3.2 Power Transmission Distribution Factors

In order to forecast actual flows on interconnections, one uses the *Power Transmission Distribution Factors* (PTDF), which measure the amount of power which would transit on a given transmission line, if 1 MW of power is injected at a given node and withdrawn at a predefined sink node. These PTDFs can be computed, based on physical characteristics of the actual network.

Let  $n \in N$  denote the set of nodes of the network, and  $a \in A$  the set of transmission lines (arcs of the network). If  $\phi_{na}$  denotes the PTDF associated to an injection at node  $n$  for transmission line  $a$  (withdrawn at the network sink), then a transaction of  $X$  megawatts, generated at some node  $n$  and delivered to a customer at node  $m$  will impact a transmission line  $a$  with a contributed flow of  $(\phi_{na} - \phi_{ma}) \times X$ . The actual flow on transmission line  $a$  will result from the sum of these contributed flows for all existing transactions on the network.

Ultimately, let  $z_n$  be the “net injection” at some node of the network (i.e.  $z_n > 0$  for injection and  $z_n < 0$  in case of withdrawal), the total flow  $f_a$  on a transmission line can be computed using one of the two formulations

$$f_a = \sum_n \phi_{na} z_n = \sum_{n,m} (\phi_{na} - \phi_{ma}) X_{nm}, \quad (8)$$

where  $X_{nm} \geq 0$  denotes the volume of transactions generated at node  $n$  for consumption at node  $m$ .

## 3.3 A Practical Example of Unexpected Results

PTDFs help quantify the actual amount of loop flows. In many recent papers on the cross-border congestion question (see for instance [3]), it is implicitly assumed that intra-regional transactions should not generate loop flows outside of the relevant regional network. This is even implicitly admitted in

Article 2(2c) of the Regulation, that refers to congestion on interconnections due to international transactions.

This assumption does probably hold (at least to a large extent) for transactions within Belgium or within the Netherlands: the German network should not be significantly affected by a Belgian generator selling power to a Belgian client. But this is certainly less clear for other regions.

We take the example of a large wind-based power generation in the North of Germany (which is one of the medium-term scenarios which is most seriously envisaged) to supply a large consuming center in the South of the country. Although this is a purely intra-national transaction (hence no cross-border trade), this massive flow of power from the North to the South of Germany definitely induces loop flows through the Netherlands, Belgium and France.

Assume that other countries do not engage cross-border transactions, and do not generate loop flows (which is reasonable for Belgium and the Netherlands, but questionable for France). We take an arbitrary value of 1 000 MW of loop flows which pass through the NL-FR axis before re-entering Germany.

Applying the compensation mechanism as defined in section 2 would yield the following results. Measured flows on interconnections show Germany exporting 1 000 MW at its border with the Netherlands, and re-importing it from France. Similarly, all other three countries import 1 000 MW from their North border and re-export them successively to Belgium, France and finally back to Germany. Hence for each of the four countries, both  $X_i$  and  $M_i$  are equal to 1 000. Each of the horizontal networks therefore hosts a transit of one thousand megawatts. Because the compensation mechanism refers to physically measured flows, and not to the intra-national or international commercial transactions, each state (including Germany) will therefore be entitled to claim a compensation up to some fraction of its LRAIC <sup>1</sup>.

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<sup>1</sup>The computation of rough estimates of LRAIC is based on European statistics of

	<b>DE</b>	<b>NL</b>	<b>BE</b>	<b>FR</b>
Load ( $L_i$ )	60 GW	15 GW	10 GW	50 GW
Generation ( $G_i$ )	60 GW	15 GW	10 MW	50 GW
Exports ( $X_i$ )	1 GW	1 GW	1 GW	1 GW
Imports ( $M_i$ )	1 GW	1 GW	1 GW	1 GW
Transit Ratio ( $\xi_i$ )	1.64%	6.25%	9.09%	1.96%
Netw.Cost ( $LRAIC_i$ )	850 M€	90 M€	50 M€	950 M€
Due Compensation	13.93 M€	5.63 M€	4.55 M€	18.63 M€
Total Fund	42.73 M€			
Net Flow ( $CANF_i$ )	0 GW	0 GW	0 GW	0 GW
To be paid ( $K_i$ )	UNDF	UNDF	UNDF	UNDF

Table 1: Compensation for the Base Case

As shown in table 1, the total compensation fund would reach over 42 M€. However, when we come to the computation of who must pay what, we realise that since all states have a zero net flow, nobody should pay anything at all, according to equation (7). In this case, the system has no solution. Not only Germany, who would be responsible for all transit in this case, would not pay a cent, but would even be entitled to claim for a compensation for hosting (its own) transit!

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the number of kilometers of transmission lines for various high voltage levels, as well as corresponding estimates of LRAIC ranges per country, in € per kilometer, provided by [4]. These figures are mentioned only for the sake of illustration and should in no case be taken actual long-run average incremental costs for the involved countries.

### 3.4 Pushing a little further...

Let us now assume that, besides the huge loop flow arising because of the supposed German intra-national transaction, French producers export a smaller amount (say, 100 MW) towards the Netherlands. Assume this creates a direct flow of 70 MW through Belgium, and a loop flow of 30 MW via the German network. The resulting situation would then be as illustrated in figure 2.

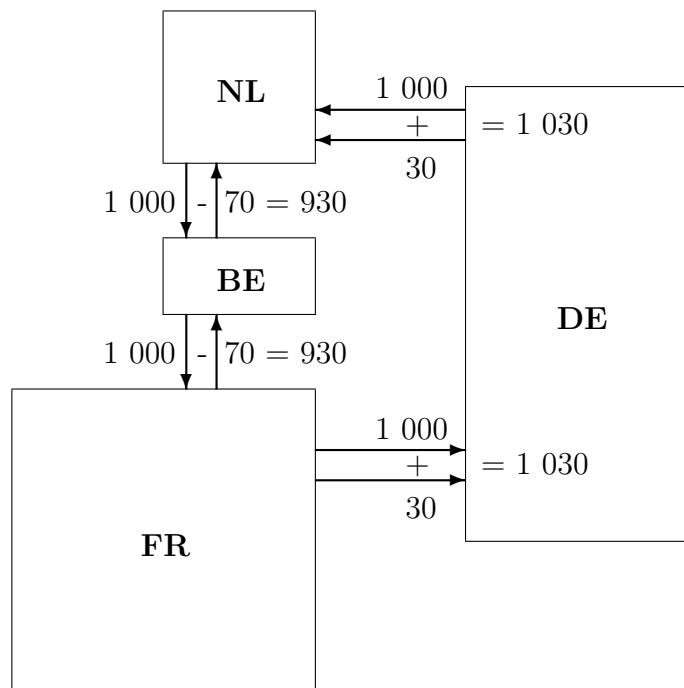


Figure 2: North-Western Europe continental network

Applying the same method on this example yields the results as displayed in table 2. France and the Netherlands are responsible for a transit of 100 MW, while Germany generates loop flows up to 1 000 MW. However, Germany does in this case not have to pay one single cent for compensation. Instead, it gets nearly a quarter of the compensation fund, which is sup-

	<b>DE</b>	<b>NL</b>	<b>BE</b>	<b>FR</b>
Load ( $L_i$ )	60 GW	15 GW	10 GW	50 GW
Generation ( $G_i$ )	60 GW	15 GW	10 MW	50 GW
Exports ( $X_i$ )	1.03 GW	0.93 GW	0.93 GW	1.03 GW
Imports ( $M_i$ )	1.03 GW	1.03 GW	0.93 GW	0.93 GW
Transit ( $T_i$ )	1.03 GW	0.93 GW	0.93 GW	0.93 GW
Transit Ratio ( $\xi_i$ )	1.69%	5.84%	8.51%	1.83%
Netw.Cost ( $LRAIC_i$ )	850 M€	90 M€	50 M€	950 M€
Due Compensation	14.35 M€	5.25 M€	4.25 M€	17.35 M€
Total Fund		41.20 M€		
Net Flow ( $CANF_i$ )	0.00 GW	0.10 GW	0.00 GW	0.10 GW
To be paid ( $K_i$ )	0.00 M€	20.60 M€	0.00 M€	20.60 M€

Table 2: Pushing further the Base Case

ported in equal parts by France and the Netherlands. The net amounts, in the end, are expenses of respectively 3.25 and 15.35 M€ for France and the Netherlands, respectively, while Belgium receives a 4.25 M€ compensation for truly hosting transit, and Germany would unduly perceive a 14.35 M€ compensation, for a transit which they are responsible for.

## 4 Conclusions

From the sample results presented in section 3, it is obvious that the Inter-TSO Compensation Mechanism, as proposed by the guidelines issued by the European Commission, suffers serious drawbacks. Not only it may lead to cases where no solution exists (although this may be disputable since the conditions required for this situation are that all cumulated absolute net flows be zero for all Member States, which is very unlikely), but we mainly have shown that the mechanism may induce undue compensations for Member States which are responsible for transit, while other States have to fully provision the Compensation Fund, when they are only responsible for a small part of the actual transit. In this sense, the guidelines offer no guarantee of satisfying neither Article 3(1) nor Article 3(2) of the Regulation.

This suggests that the Inter-TSO Compensation Mechanism be studied somewhat further, before the Guidelines of the European Commission becoming mandatory.

## References

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