Imbalance Management TenneT

Analysis report

Analysis participants:

TenneT NL
TenneT DE
E-Bridge
GEN Nederland

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Reference documents

Documents used for the analysis of UCTE criteria for balancing systems:

- UCTE handbook P1 – Policy 1: Load-Frequency Control and Performance [C], version 3.0, 01-04-2009

This document is available from the ENTSO-E website: www.entsoe.eu

Documents used for the analysis of the Dutch balancing system:

- *Handleiding bieden Regel en ReserveVermogen_tcm41-19020.pdf*
- *MO 10-077 Uitvoeringsregels 4.0_tcm41-19026.pdf*
- *Productinformatie herstelvoorziening_tcm41-17913.pdf*
- *Productinformatie noodvermogen_tcm41-17915.pdf and tcm41-18781.pdf*
- *Systeemcode_28_februari_2009_tcm7-127999.pdf*

These documents were downloaded from: www.tennet.org on the 23rd of December 2010

Data used for the quantitative analysis of the Dutch balancing system:

- *Data sheet example.xls, supplied by TenneT NL on 14-02-2011*

Documents used for the analysis of the German balancing system:

- *2010 12 22 Control Power in Germany.pdf, supplied by TenneT DE on 23-12-2010*
- *TC2007_D2-1_2009_End.pdf, supplied by TenneT DE on 23-12-2010*
- *TransmissionCode-2007_Anhang-D3_englisch.pdf, supplied by TenneT DE on 23-12-2010*
- *Transmissioncode 2007_engl.pdf, supplied by TenneT DE on 23-12-2010*

Data used for the quantitative analysis of the German balancing system:

- *TenneT_Data_sheet_20110118.xls, supplied by TenneT DE on 19-1-2011*

General documents used as input for this analysis:

- *20100920_Workshop imbalance management DK.doc*
- *20100920_Workshop imbalance management.ppt*
- *Extract_from_OP_Handbook_Control_Quality_16_09_2010.doc*
- *Comparative study_TenneT_ 20100702.ppt*
- *LFC_report_Q1_2010.pdf*
- *Report_Dutch_imbalance market_15022010.pdf*

These documents were distributed among the analysis participants during course of the analysis, from the 20th of September 2010 till the 30th of April 2011.

Management summary

Technical characteristics require that demand for- and supply of power are to be in continuous balance. Although the power balance is principally maintained by market transactions, market imperfections and technical disturbances cause imbalances. In their role of system operators, TenneT NL and TenneT DE (formerly Transpower) correct for imbalances using a system of control power reserves. Although UCTE policy describes a pan-European standard for these systems, national implementations differ significantly. The merger between TenneT NL and Transpower offers an opportunity to analyse the differences in performance between the imbalance management systems in Germany and in the Netherlands.

This document contains the results of a comparative analysis of the imbalance management systems used by TenneT NL and Tennet DE. Prior analysis[1] concluded that the imbalance system operated by TenneT NL seems to have a higher macro-economic efficiency compared to the system operated at TenneT DE. This report contains the results of a follow-up analysis which focused more on the technical quality of both systems.

A descriptive qualitative analysis of both systems reveals several differences in the manner in which required control capacities are calculated and contracted from market parties. One such difference is that in the Netherlands, market parties have an incentive (imbalance prices and bid ladder system) to assist the TSO in correcting imbalances ('passive contribution'), largely attributable to the institutional organization of the system. In Germany, TenneT DE controls all corrections in its control area using previously contracted capacity without assistance from market parties.

In addition to the qualitative analysis, a quantitative comparative analysis set out to compare the robustness of both systems was performed using data provided by TenneT NL and TenneT DE for Q1 and Q3 of 2010. Key performance indicators used in this comparison are;

- The relative amount of imbalance experienced in the two control areas,
- The total control capacity (MW) available to the respective TSOs;
- The total activated control capacity (MW) and energy (MWh);
- The total activated control capacity compared to total availale capacity;
- Area Control Error (ACE): market imbalance minus TSO control measures;
- Control capacity, control power and balancing energy costs.

The primary conclusions and observations based on the analysis are the following;

<u>Balancing performance of the market</u>

- ➢ In the Netherlands, market parties create a lower imbalance volume than in the TenneT DE area. Hence, in the Netherlands less control energy is required by the TSO.

<u>Economic performance</u>

- ➢ The relative balance management costs in the Netherlands are lower than in the TenneT DE area. This conclusion is based on the following observations:

[1] *Imbalance Management in the Netherlands and Germany, a comparative study, by E-Bridge and GEN Nederland BV, march 2010*

- There is less activated control energy in the Netherlands, due to a lower initial imbalance;
- The average control energy prices are lower in the Netherlands;
- There is less contracted control capacity in the Netherlands;
- The control capacity prices (€/MW available) in Germany and the Netherlands are comparable,

Imbalance system controller effectiveness

- TenneT DE appears to have an operating practice that allows for a higher input (imbalance) volatility, based on the relatively lower ACE in the TenneT DE area compared to the Netherlands.

Main recommendations:
Discussions about the possible causes for these observed differences mainly point towards the institutional differences determined in the qualitative system analysis. Provided with this insight in the different control power market structures, products and information exchanges, the following recommendations are made;

1) Reduce control energy costs by introducing more flexibility and competition in the bidding process in Germany:

- Accept control energy bids of pre-qualified parties that are not participating in the supply of contracted capacity;
- Introduce more flexibility in bid pricing (allow changes up to 1 hour prior to delivery, prices per PTU).

2) Reduce the required control energy in Germany by reducing the imbalance of market parties:

- Educate BRPs about the benefits and importance of reducing imbalance;
- Re-evaluate BRP incentives:
    - Enable reduction of system imbalance using passive contribution of BRPs by considering to share more real-time system balance and balance energy price information with the market;
    - Prevent creation of additional imbalance caused by arbitrage opportunities for control energy suppliers. Consider to introduce marginal control energy pricing.

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List of acronyms and abbreviations

ACE	Area Control Error. The control area's imbalance minus its activated control power per PTU.
APX	Amsterdam Power Exchange (APX) is an international power and gas exchange on which acknowledged market parties trade energy. The APX settles the Dutch day-ahead spot market.
BRP	Balance Responsible Party. A market party which is acknowledged by the System Operator as program responsible and is allowed to execute program responsibility.
CA	Control Area, is an electrical system bound by interconnection metering and telemetry. It balances its generation directly in exchange schedules with other control areas and contributes to frequency regulation of the system as a whole.
EEX	European Energy Exchange (EEX) is an international power and gas exchange on which acknowledged market parties trade energy. The EEX settles the German day-ahead spot market.
EHV	Energy High Voltage grid.
EnBW TNG	Energie Baden-Württemberg Transportnetze
HOBA	Horizontaler Belastungsausgleich, HOBA basically fixes the balance responsibility for renewable energy in-feed of each of the four TSOs as a constant share of total renewable energy in-feed in real time.
Imbalance	The imbalance of the Control Area is the difference between the measured cross border power exchanges and the scheduled exchanges before control power activation.
NRV	Netzregelverbund, combination of four German control areas into a single virtual control area.
N-1 criterion	The (n-1) criterion refers to a level of redundancy in the system, which is purposefully maintained as a safeguard against failures. A system is n-1 redundant if the loss of 1 (system-) component, such as a power line, does not result in system failure.
Marginal Price	Also known as uniform price model. Marginal prices arise from collecting all bids for a specified control action and determining a uniform average price for all suppliers of control power.
PCR	Primary Control Reserve. Local automatic control system which delivers reserve power to counter frequency change.
PTU	Program Time Unit, which is 15 minutes.
Pay-as-bid	Also known as discriminatory pricing. In a pay-as-bid pricing model all suppliers of control power receive the price included in their individual bids when called to supply control power.
SCR	Secondary Control Reserve. Centralized automatic control which delivers reserve power in order to replace the need for frequency restoration reserves (PCR) and bring interchange programs to their target values.
TCR	Tertiary Control Reserve. Manual change in the dispatching and unit commitment in order to restore the secondary control reserve, to manage potential congestions, and to bring back the frequency and the interchange programs to their target if the secondary control reserve is not sufficient.

1 Introduction

1.1 *Context*

In the European power markets, Transmission System Operators (TSO's) are responsible first and foremost for a secure and reliable transport of electricity through the transmission grids they operate. In recent years, their focus has shifted towards a more macro-economic perspective of the costs incurred to balance the system. Moreover, TSO's have the responsibility to improve the efficiency of the energy markets they facilitate, in cooperation with their respective national regulators.

During the past decade the national electricity markets have increasingly been coupled and integrated, following the common European perspective of a single internal electricity market. This ongoing integration requires investments in the technical infrastructure, such as cross-border interconnection capacity, as well as cooperation and harmonization of policies between the TSO's. An example of the latter is the way the different TSO's manage to balance their systems. Although a European policy is documented, imbalance management systems have been designed and implemented differently in various European countries. Such differences between the German- and Dutch systems became more apparent following the merger between TenneT and Transpower in 2009. The resulting availability of knowledge and comparative empirical data on the different approaches after the merger, presents an opportunity to compare the relative merits of both systems in an objective analysis.

1.2 *Goal and relation to earlier work*

This particular analysis is a follow-up of an earlier analysis conducted in the first quarter of 2010, using system and market data of 2008/2009. This earlier analysis is focused on a financial comparison of the German and Dutch imbalance systems. The main conclusion of this analysis is that the Dutch balancing model seems economically more attractive when compared to the German model. Moreover, the Dutch balancing mechanism seems likely to reveal higher-level macro-economic efficiencies and the passive contribution of decentralized market parties seems to create more competition without jeopardizing the system's stability.

Although both systems are well capable of balancing the grid, these financial differences have to be related to the technical quality with which the respective TSO's balance their grid. This follow-up analysis focuses on the relative quality of the German and Dutch balancing systems and therefore focuses on a more technical comparison of their relative performance. In this document the technical quality of the imbalance management systems is defined as and covered by the characteristic 'robustness'. As such, the objective of this research is to develop an objective comparison of the relative merits of the German and Dutch balancing systems, using neutral criteria which define the characteristic robustness.

In addition to the technical analysis, the financial analysis was repeated using the more recent 2010 market data and specific TenneT control and imbalance power data that was not available at the time of the earlier analysis.

1.3 *Approach*

This report is divided into four segments. The first part provides a description of the concept of imbalance management mechanisms and includes a qualitative comparison of the German and Dutch implementations of these systems. This part also describes the scope of the analysis in higher detail. Based on this system description, the second part of this report describes the analysis method by defining a set of neutral criteria required to measure and compare the relative technical performance of the two systems. These criteria are subsequently used to perform the quantitative analysis of the technical quality or ‘robustness’ of both systems. This analysis includes both publicly available data as well as recent sample data provided by TenneT DE and TenneT NL. Chapter four presents the results of this quantitative analysis, while the final chapter of this report provides interpretations and a discussion on these quantitative results, resulting in conclusions and recommendations.

2 System description

In order to compare the technical performance of both the Dutch and German balancing systems, the characteristics and criteria that define the robustness of a balancing system need to be defined. This chapter provides a general and qualitative description of balancing systems as well as the specific technical and organizational characteristics of the German and Dutch systems. This description is used to determine the scope and boundaries of the quantitative comparative analysis laid out in this report.

2.1 *Imbalance management*

Because large volumes of electric energy cannot be stored with economic efficiency, power supply and demand have to be matched continuously. Sudden (power outages) or continuous (imbalance) disparities between supply and demand negatively affect power quality and can, if left uncorrected, harm consumer appliances and the infrastructure itself. These imbalances can result from unexpected failures, e.g. power plant outages, but can also be the result of inherent market imperfections.

If the market projects demand well, the need for balancing would be small. But actual power flows between supply and demand (allocations) generally do not perfectly match planned volumes (nominations). In addition, the economic objectives of market participants may not always coincide with the technical objective of the TSO, which is zero imbalance. The result is a system imbalance position of the market in its entirety. This is depicted in figure 1. The market result leads (due to imperfections) to an initial result that constitutes imbalance for the TSO. This input is a control target for the TSO. Using the means at its disposal (the focus of this analysis) the TSO reduces its initial control target. The resulting sum is the ACE.

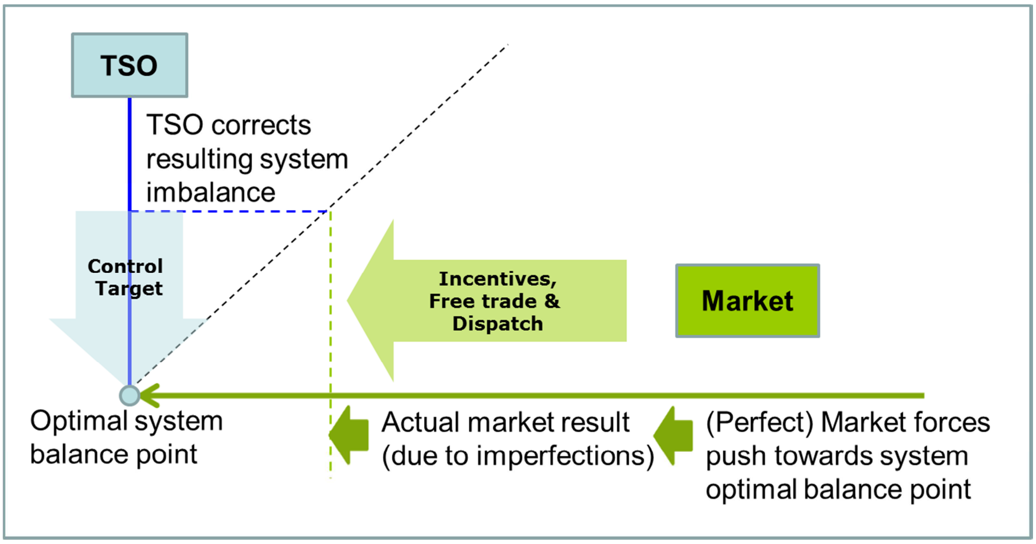

Figure 1: Imbalance as a market outcome – TSO control target

The TSOs are responsible for maintaining system balance and hence for correcting for the imperfect market result. In order to do so, TSOs use a system of control reserve capacity and energy. This reserve capacity (in MW's) can be activated when encountering disturbances or imbalances. Depending on the type of imbalance, positive or negative, the activation of these reserves would result in production plants respectively reducing or increasing their energy output to restore the overall system power balance.

2.2 *Control power products*

Because all TSO control areas within the ENTSO-E (formerly UCTE) area are interconnected, disturbances affect system performance of the pan-European power system. For this reason pan-European UCTE policy specifies a system of control reserves and common technical boundary criteria to which individual national implementations must adhere. TSO's are responsible for the system's power balance by maintaining and activating primary, secondary and tertiary control reserves in response to disturbances. As represented in Figure 2, these reserves are called in sequence.

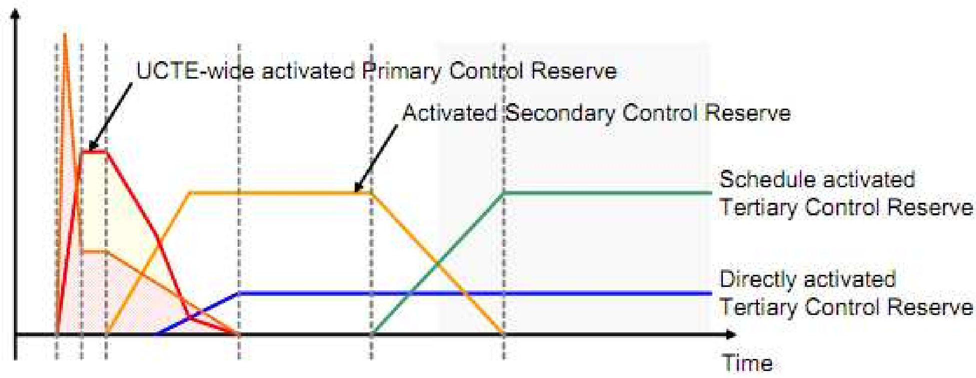

Figure 2: Sequential activation of the different control reserves after a disturbance (UCTE handbook P1 – Policy 1: Load-Frequency Control and Performance [C]).

Primary control reserve power (PCR)
All ENTSO-E members are interconnected in one synchronous area and share an optimal system frequency of 50 Hertz. System disturbances in any member's control area are noticed in the form of frequency deviations throughout the entire ENTSO-E area. Deviations in excess of tolerable limits automatically trigger the activation of PCR reserve capacity throughout the entire ENTSO-E region.
<u>Capacity:</u> Each TSO is obliged to maintain a minimum share of the European total of 3000MW PCR capacity, proportional to the size of the TSO's CA within the entire synchronous ENTSO-E area. The manner in which these capacities are contracted differs between member states.
<u>Response time:</u> UCTE criteria prescribe ramping speeds of 15 seconds to 50% of capacity, and 30 seconds to 100% capacity.

Secondary control reserve power (SCR)
SCR capacity is intended to replace the use of activated PCR capacity within one PTU. SCR is activated in the control area of the TSO which experienced the disturbance to restore system optimal frequency as well as to keep the power interchanges between TSO control areas within programmed scheduled values.
<u>Capacity:</u> According to the UCTE criteria, different methods for sizing SCR power capacity may be used, which can lead to different results. The probabilistic and the deterministic approach are used later on to exemplify this. Detailed explanations of these methods can be found in the UCTE handbook.
<u>Response time:</u> According to the UCTE criteria, SCR has to be activated within 30 seconds, without overshoot of ACE and must be completed within one PTU. Usually SCR is activated through an automatic signal leading to response times within five minutes.

Tertiary control reserve power (TCR)
Tertiary control reserve (TCR) power is used to replace activated SCR power in order to restore the n – 1 criterion by guaranteeing the availability of SCR

capacity for new unplanned disturbances. Additionally, the dispatch of TCR capacity is used to distribute the required (SCR) control power to the various generators in the best possible way, in terms of economic considerations.

Response time: TCR is either activated directly or by schedule. Direct activation may be needed to replace 'lost' SCR capacity following an event (hence similar criteria as apply to SCR). Scheduled activation of TCR is contracted in the form of energy volumes per PTU (15 minutes) and may be contracted (far) in advance of actual activation.

Focus on Secondary and Tertiary control reserves

PCR is an initial and automatic response to imbalances, which is activated by all TSOs throughout the entire ENTSO-E area. The secondary and tertiary control reserves are used to supplant the use of PCR within individual TSO control areas. This report is principally concerned with the relative performances of SCR and TCR at TenneT NL and TenneT DE.

2.3 *German and Dutch imbalance management systems*

Depending on the size of the expected or average occurring imbalances, TSOs need a certain reserve of operational required available control capacity. The required control reserve capacity, or the energy volume contracted in case of TCR, needs to be contracted on the market. The manner in which these energy volumes are calculated and contracted differs depending on the model implemented in each country. Although both the Dutch and German implementations of control reserve products fall within UCTE specified boundaries, technical and institutional differences can be observed.
An example of technical differences is the manner in which total required reserve capacities are calculated or the way and the speed with which these reserves and energy volumes are activated.
Institutional differences are found in legislation, market structures and any other form of organization intended to structure the operation of the systems. This section provides an outline of the technical and institutional differences between the two systems.

2.3.1 Technical characteristics

The technical differences observed between the German and Dutch systems have been summarized per control power product in tables 1 to 3 below.

Table 1: Primary Control Reserve technical boundary conditions

	DE	NL	EU
Volume	Frequency deviation determines volumes	Reaction is defined as a proportion of frequency deviation.	-
Activation	Control signal	Control signal	All parties involved; exceeding ±20 mHz frequency deviation
Reaction	30 seconds to 100% of target value	30 seconds to 100% of target value	15 sec to 50%; 30 sec to 100%
Accessibility	Tenders	Obligation	-
Participants	Tender block size 5 MW	All units > 60MW for 1% of total capacity	-

In the Netherlands PCR is a mandatory and unpaid service. Each single production facility with a capacity greater than 60 MW has to contribute 1% of its capacity as PCR by law (for example, a 600 MW rated power plant must supply 6 MWs of PCR capacity). In the German balance model all control power is activated by the TSO. In Germany PCR is contracted by auction.

Table 2: Secondary Control Reserve technical boundary conditions

		DE	NL	EU
Definition		Compliance according to agreed schedules with other control areas	Replace PCP or eliminate capacity issues	Replaces PCP over minutes
Activation		Signal	Signal	Only by TSO
Reaction		5 minutes	7% of bid size per minute	-
Accessibility	**Capacity**	Monthly capacity tenders (positive + negative separately).	- Yearly tender for 300 *MW* base capacity; - symmetrical bids; up and down regulation	-
	Volume	Tender specifies both capacity and energy bid; Selection on capacity bid.	- Daily symmetrical energy bids per PTU in *MWh*'s separate from capacity tender.	-
Block sizes		Tender block size -10MW/+10MW	Minimum bid size 4MWh, maximum 200MWh	-

Table 3: Tertiary Control Reserve technical boundary conditions

		DE	NL	EU
Definition		Combination of direct activation and scheduled activation	Scheduling	Complements and finally replaces SCR
Activation		By telephone call	By messaging	by manual action at any time
Reaction		Within 15 minutes	Within 15 minutes	15 minutes
Accessibility	**Capacity**	Daily capacity tenders (positive + negative separately)	- Yearly tender for 300 *MW* load-shedding capacity	-
	Volume	Tender specifies both capacity and energy bid; Selection on capacity bid.	- Auction per PTU in *MWh*'s	-
Total amount		-15MW/+15MW	±20MW to ±25MW	-

The Dutch balancing systems incorporates scheduling of TCR. TenneT NL has 300 MW asymmetric contracted TCR (load shedding only) and on average TenneT NL has approximately 50 MW TCR that can be activated through calling of bids as a result of a daily auction. TenneT NL states that the contracted TCR is hardly ever used (less than 3% of the yearly called TCR volume).

TenneT DE utilizes a combination of TCR that is directly activated and TCR that is activated through scheduling. The schedule activated TCR is activated within 15 minutes of initial call. This is a mixed model in which power is activated directly but in which TenneT DE only pays for the scheduled amount. Directly activated TCR power is used mainly to avoid black-outs.

2.3.2 Institutional characteristics

Apart from the differences in technical characteristics, there are institutional differences between the two models. Among others, notable differences can be observed in the way capacity contracts (MW) are acquired from the market and the way these market parties are remunerated for activated control energy (MWh). These differences have been summarized in table 4 below.

Table 4: Comparison between Dutch and German Balancing Model

Criterion	NL	DE
1. Market characteristics		
Tender of SCR	SCR: yearly tender for capacity (symmetric bids).	SCR: monthly tender for capacity.
Tender of TCR	TCR: yearly tender for capacity (controllable loads for up-regulation). Daily energy bids, which can be changed up to one hour before execution, at which point these bids become firm.	TCR: daily tender for capacity (six windows of four hours each). Bidders specify capacity price and energy price valid for the entire tendering period; selection of bids is based on capacity price only.
Monitoring of availability	No systematic monitoring mechanism implemented.	No systematic monitoring mechanism implemented.
Liquidity	SCR: low TCR: low	SCR: low TCR: satisfactory
2. Contracted capacity characteristics (MW)		
Remuneration capacity	Pay-as-bid.	Pay-as-bid.
Transparency capacity prices	Results not public information.	Results published following the auction.
Adjustment of capacity prices	Not possible after the auction has ended.	Not possible after the auction has ended.
3. Activated control energy characteristics (MWh)		
Remuneration energy	Uniform marginal price.	Pay-as-bid.
Transparency energy prices	Bid-ladder published day-ahead (but bids may be changed intra-day). Result of bid activation is published real-time along with long/short information in CA).	Bid-ladder is known when auction results are published and cannot change. No information on activated bids of long/short position in CA is published.
Adjustment of energy prices	Possible up to one hour before real-time.	Not possible after the auction has ended.
4. Information and Responsibility		
Imbalance transparency	Published a day after.	Published after several weeks.
Imbalance price symmetry	Dual pricing, if both negative and positive control reserves are activated: two prices in one PTU (price for long BRPs is different from price for short BRPs).	Single price during each PTU for long and short BRPs.
Balance responsibility	100% (all market parties are balance responsible)	TSO is balance-responsible for a large share of the market (i.e. wind power).

Control energy price

The pricing systems for control energy are different in the Netherlands and Germany. In the Netherlands, marginal pricing is used, while in Germany the volumes are pay-as-bid. In marginal pricing, also known as uniform pricing, prices arise from collecting all bids for a specified control action and determining the highest price as a uniform price for all activated control energy. In the German pay-as-bid pricing model, also known as discriminatory pricing, all suppliers of control power receive the price included in their individual bids when called to supply control energy.

Theoretically, where the first system induces an auction with the costs of production as starting point for the prices, the latter system needs prices which include the production costs as well as the margins.

Balance energy price
In the German system the costs of all activated control power bids are aggregated to calculate the average imbalance price. As a result the first activated bid has a lower price and the last activated bid has a higher price than the imbalance. In the Dutch balance model the difference between the regulated power price (bid) and the imbalance price is zero, except in periods of activated incentive component when this is a constant. For the German model, there are non-zero differences.

In the Dutch imbalance management system control area imbalance positions and imbalance price are made public in near real-time. Therefore all market participants have the opportunity to voluntarily contribute to the TSO's efforts in maintaining the system balance. This so called 'passive contribution' is believed to result in a substantial reduction in the required control energy.

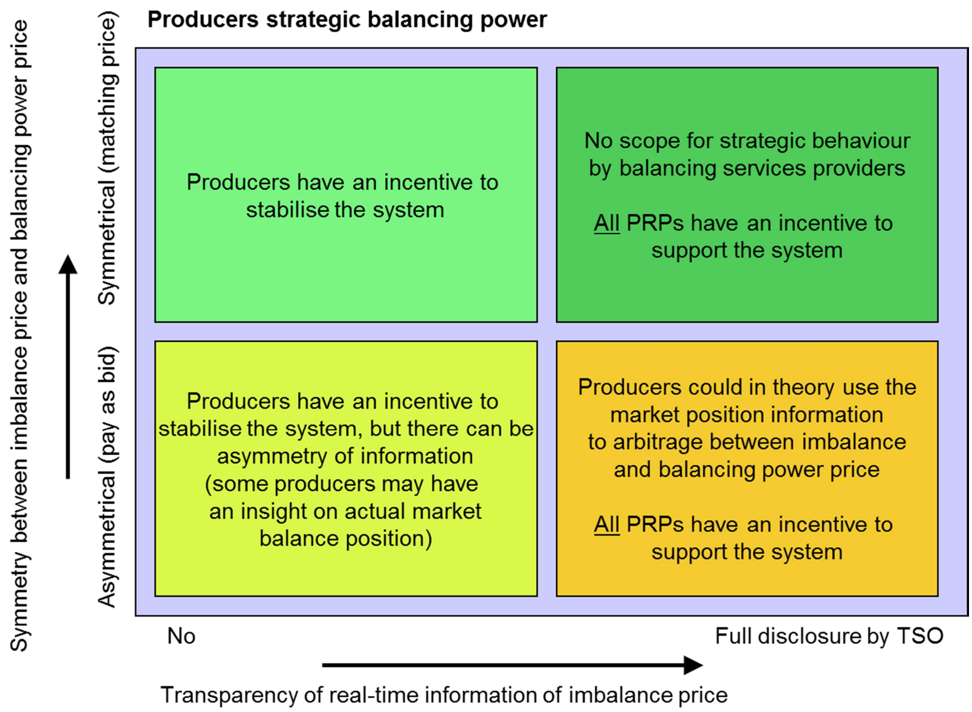

Figure 3: The different institutional choices for the imbalance system

Market behavior defined by institutional choices
The average transactions on the market for control reserves should be more attractive than average transactions on the wholesale market. Otherwise the power capacities and volumes would be offered to the market. For imbalance settlement (which is compulsory) the opposite should be true. It should be less attractive to have a transaction on the imbalance market than one on the whole sale market. Non-response to a request for control reserves should not be rewarded better than the corresponding 'penalty' for imbalance.

In the Dutch imbalance management system control area imbalance positions and imbalance price are made public in near real-time. Therefore all market participants have the opportunity to voluntarily contribute to the TSO's efforts in maintaining the system balance. This so called 'passive contribution' is believed to result in a substantial reduction in the required control energy. Figure 3 shows that producers could use an asymmetrical system to arbitrage between imbalance and balancing power prices.

3 Analytic approach

As discussed in the introduction the goal of this analysis is to compare the Dutch and German balancing management as described in the previous chapter. In order to compare both systems, commonly shared performance indicators must be defined. These must be indicative of the technical quality, robustness and financial performance of both systems. This chapter first discusses how a common performance indicator was identified and subsequently discusses how and by using what data these systems were analyzed. The results of this quantitative analysis are presented in chapter 4.

3.1 *Technical quality of imbalance systems*

The characteristics described in the previous chapter, and those listed in tables 1 to 4, are mainly of a qualitative nature. This chapter focuses on the definition of quantitative criteria that can be related to the quality of an imbalance management system. The robustness of the controller is believed to be a good indicator of the system's technical quality.
To research the robustness of the imbalance management systems described in the former paragraphs, the definition of robustness must be determined. Technologically, the definition of robustness is derived from the performance of a controller. A controller is robust when it does not vary its output under influence of noise due to missing or wrong input values. A control loop can be created for most technical and economical processes. Therefore the controller is used as an analogy for the balancing system. This is depicted in Figure 4.

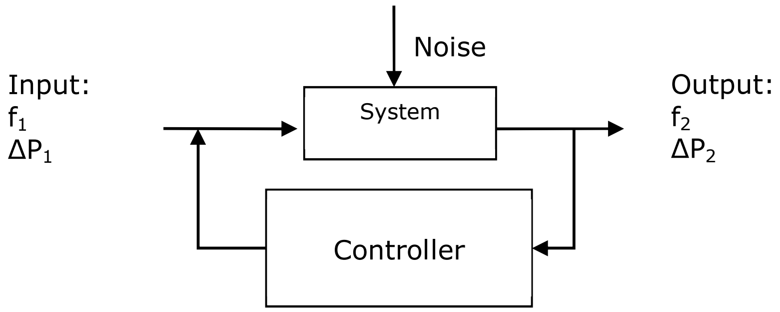

Figure 4: The imbalance management system as a controller

From a technical point of view robustness is related to the effects of noise. When considering a balancing management system, noises include market errors, renewable energy (wind/solar), incidents and plant scheduling behaviour. Robustness of the balancing system includes specific indicators such as the Area Control Error (ACE).

When balancing an electricity grid, the momentary difference between supply and demand must be zero. An imbalance management system actively controls the supply and demand to reduce the actual difference towards zero. However, the balancing models implemented in the Netherlands and Germany are not perfect and will leave an error. This error is called Area Control Error, abbreviated ACE. The ACE is the difference between the measured power exchanges and the scheduled exchanges, i.e. imbalance minus the requested control power.

The goal of an imbalance management system is to minimize ACE. By minimizing the ACE in the TSO's control area, the frequency of electricity remain constant and the cross border exchanges of power remain as scheduled. As a general definition, the definition of ACE provided above may be inadequate because it does not take the specifics of the Control Area (CA) into account. However, when the specifics and the differences between the different CAs are known beforehand these can be compensated for. In order to compare the Dutch and German balancing systems, this definition of robustness and its performance indicator ACE are believed to be a good indication of the systems' (relative) qualities.

3.2 *Method & empirical data*

The analysis of the performances of TSOs TenneT DE and TenneT NL is divided into the following four sections;

1. Available control power capacity;
2. Market imbalance and noise;
3. Area Control Error;
4. Control and Balancing energy costs.

The nature and intent of each sub-analysis are described below.

3.2.1 Control power capacity

As mentioned in chapter 2, the causes of imbalance can be found in both disturbances such as outages, but also more generally as a result of imperfect market results, the difference between market nominations and the energy allocation. If the market projects demand and supply well, the need for balancing will be small, but actual power flows between supply and demand (allocations) generally do not match planned volumes (nominations) perfectly. To be able to correct these imbalances, TSOs have an operational required control power capacity available. This question is concerned with the available control power capacity at TenneT DE and TenneT NL.

- What are the available control power capacities of TenneT DE and TenneT NL?
- What are the relations between the available control power and the imbalances occurring in the respective CA's:
    a. Average imbalance as a fraction of the available control power.
    b. Occurrence of imbalance as a fraction of the available control power.

3.2.2 Market Imbalance

Secondly, the actual imbalances need to be corrected by the TSO. In order to compare both systems the amount of imbalance experienced in both control areas is analyzed. For both the Dutch and German systems the absolute and relative imbalances are analyzed. Because in Germany the share of renewables is considerably larger than in the Netherlands, they may contribute greatly to system imbalance. This effect has accounted for in the analysis of the German data.This leads to the following questions:

- How much imbalance was experienced in the control areas of TenneT NL and TenneT DE?
- There are systematic imbalances in the hours where the volume demand in the market increases or decreases rapidly, i.e. morning and evening. This is caused by the fact that production is scheduled in hourly blocks and demand is allocated per PTU. What is the delta imbalance per hour?

3.2.3 Area Control Error (ACE)

Imbalances are (partially) corrected by the TSOs using the control reserves at their disposal. Control energy is activated towards the control target (optimal system balance point in Figure 1) as much as possible, but will generally leave a margin of error. This remaining area control error is an indicator of the effectiveness of the control actions by the TSO. As defined previously the performance indicator ACE is thought to provide a good indication of the systems' (relative) qualities as both TSOs will have attempted to minimize their respective ACEs.

- What are the absolute and relative ACE volumes in the TenneT DE and TenneT NL control areas?
- What are the control areas' average delta ACEs, and how these figures relate to their respective delta imbalance per hour?

3.2.4 Balance management costs

The utilization of balancing regulation has its costs. Part of the costs occur before delivery in the form of contracted control capacity. After delivery the activated control energy costs are settled with the producers, and the imbalance energy costs are settled with the BRPs.

To be able to compare the incurred costs of the TenneT NL and TenneT DE control areas, all prices are presented as a delta price relative to the day-ahead power exchange prices. In the Netherlands these exchange prices originate from the APX, and in Germany from the EEX.

- What are the respective delta control energy costs in the control areas of TenneT DE and TenneT NL?
- What are the respective delta imbalance energy costs in the control areas of TenneT DE and TenneT NL?
- What are the costs of the contracted control capacity in the TenneT DE and TenneT NL control areas?

3.2.5 Empirical data used in the analysis

TenneT DE and TenneT NL made 15 minute interval data available to be used in the analyses described before (see Reference documents). These datasets contain data for the 1st Quarter of 2010 and the 3rd Quarter of 2010, for both TenneT DE and TenneT NL. Both quarterly datasets are used to compare relative performance of the systems. The datasets were analysed using specific time series data analysis tooling (GEN eBase software) and MS Excel.

4 Analysis results

The quantitative analyses described in chapter three are performed using the datasets discussed under the paragraph reference documents. This chapter presents the results and observations of the quantitative analyses. Interpretations and conclusions regarding the quality and robustness of both balancing systems are subsequently discussed in chapter five.

4.1 *Control power capacity*

In the Netherlands a fixed control capacity is contracted for a whole year. But, market parties can bid additional capacity in the daily control power auction which is included in the bid-ladder for control energy. One hour before delivery these additional bids become firm and can therefore be considered as contracts for which the capacity payment is zero.

In Germany a fixed capacity is contracted per month (secondary control) or daily (primary control) for the whole NRV region, of which a specific fraction is appointed to be contracted by TenneT DE. Because of the pooling of control capacity with the other three German TSOs the contracted capacity of TenneT DE is lower than the required control capacity in case of no pool.

Table 5 Control power capacity NL

TenneT NL		2010Q1	2010Q3
Contracted capacity [MW] (fixed capacity, yearly tender)	UP	600	600
	DOWN	300	300
Available capacity [MW] (average of all available control power bids)	UP	961	849
	DOWN	769	686

Table 6 Control power capacity DE

TenneT DE		2010Q1	2010Q3
Contracted capacity [MW] (contracted fraction of TenneT DE in NRV pool, monthly/daily tender)	UP	1594	1733
	DOWN	1205	1349
Theoretical capacity [MW] (in case TenneT DE would not participate in the NRV pool)	UP	1934	2102
	DOWN	1471	1701
Total pool capacity [MW] (theoretical max of NRV pool)	UP	3972	4478
	DOWN	3820	4342

An indicator for the robustness of an imbalance management system is effective utilization of the available control power capacity by comparing these to the average imbalance occurrences. The resulting average percentage of the imbalance volume compared to the available control capacity per PTU is presented in the next table.

Table 7 Average imbalance / control capacity

Average imbalance / control capacity (based on 15 min interval data)	2010Q1	2010Q3
TenneT NL Using available capacity	14%	16%
TenneT DE Using contracted capacity	34%	35%
TenneT DE Using theoretical capacity	28%	28%
TenneT DE Using total pool capacity	13%	11%

Another robustness indicator of an imbalance management system is the number of occurrences of PTU's where the imbalance as fraction of the available control power exceeds a certain percentage. The following table shows the occurrences of imbalance fractions >10%, >50% and >90% of available control power as time in hours.

Table 8 Occurence of imbalance as a fraction of available control power

# Hours with Abs(Imbalance/Available control capacity) > X%	Interval X	2010Q1	2010Q3
TenneT NL Using available capacity	> 10% > 50% > 90%	1110 53 5	1269 72 5
TenneT DE Using contracted capacity	> 10% > 50% > 90%	1813 488 79	1707 529 166
TenneT DE Using theoretical capacity	> 10% > 50% > 90%	1741 303 23	1595 366 81
TenneT DE Using total pool capacity	> 10% > 50% > 90%	1188 3 0	952 12 0

Figures 5 to 8 on the next page show the available contracted control power capacity in the control areas of TenneT NL and TenneT DE in the first and third quarters of 2010. They are presented at identical scale.
The orange segments in figures 5 and 6 represent the available control power for TenneT NL which is offered by market parties. These bids for control energy (per PTU) can be altered by market parties up to the point at which they become firm, which is one hour before execution. There are no separate capacity availability payments involved in these transactions.

Figures 9 and 10 on the subsequent page present ordered relative CA imbalance values compared to the available control capacity

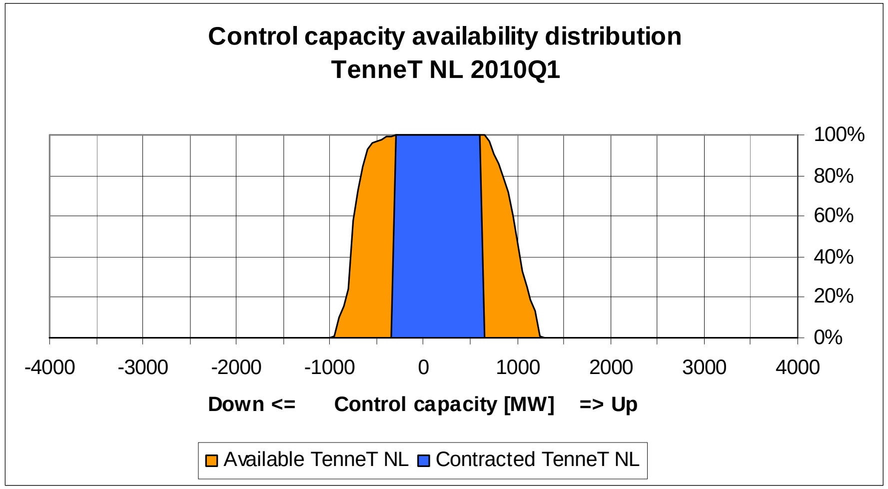

Figure 5 Control capacity availability NL Q1

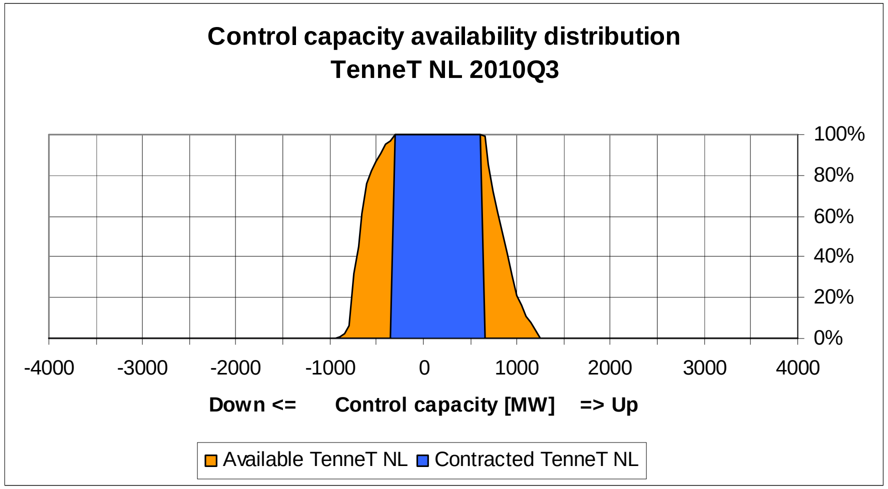

Figure 6 Control capacity availability NL Q3

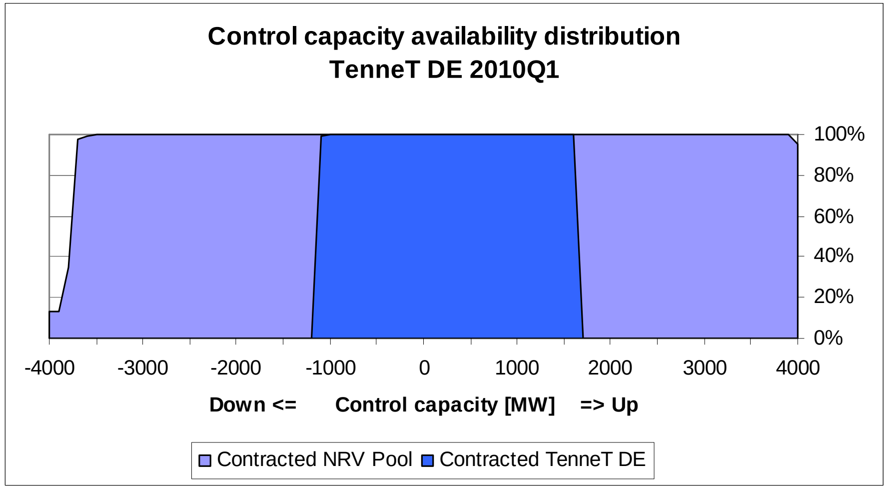

Figure 7 Control capacity availability DE Q1

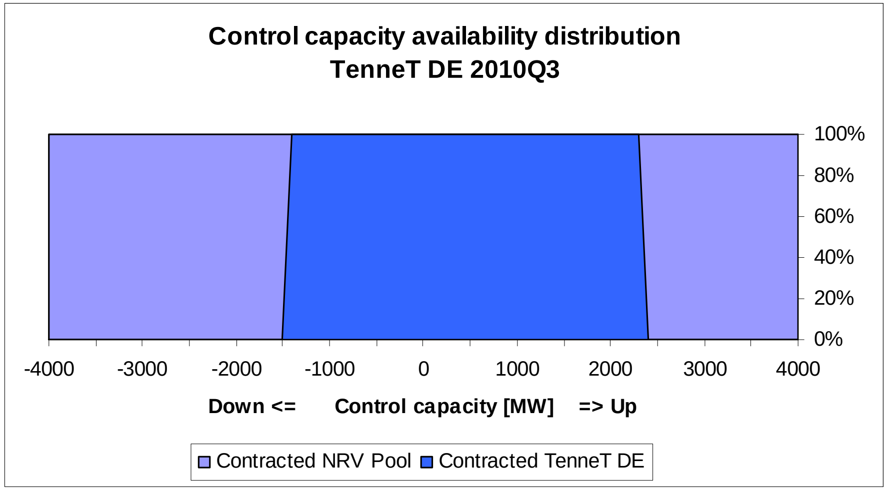

Figure 8 Control capacity availability DE Q3

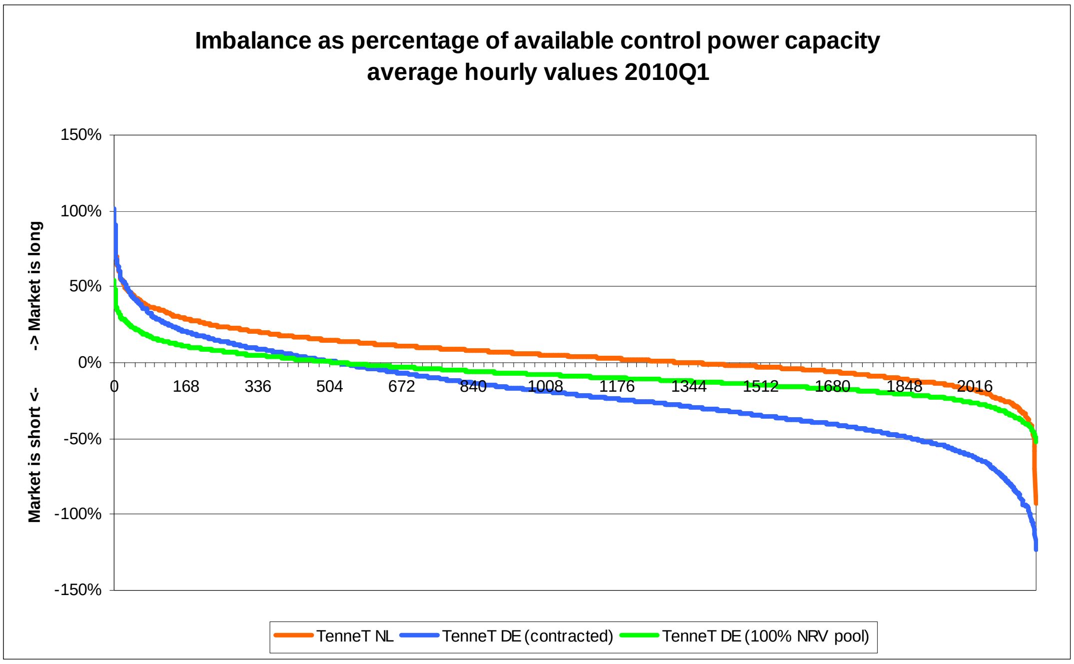

Figure 9 Imbalance as percentage of control power Q1

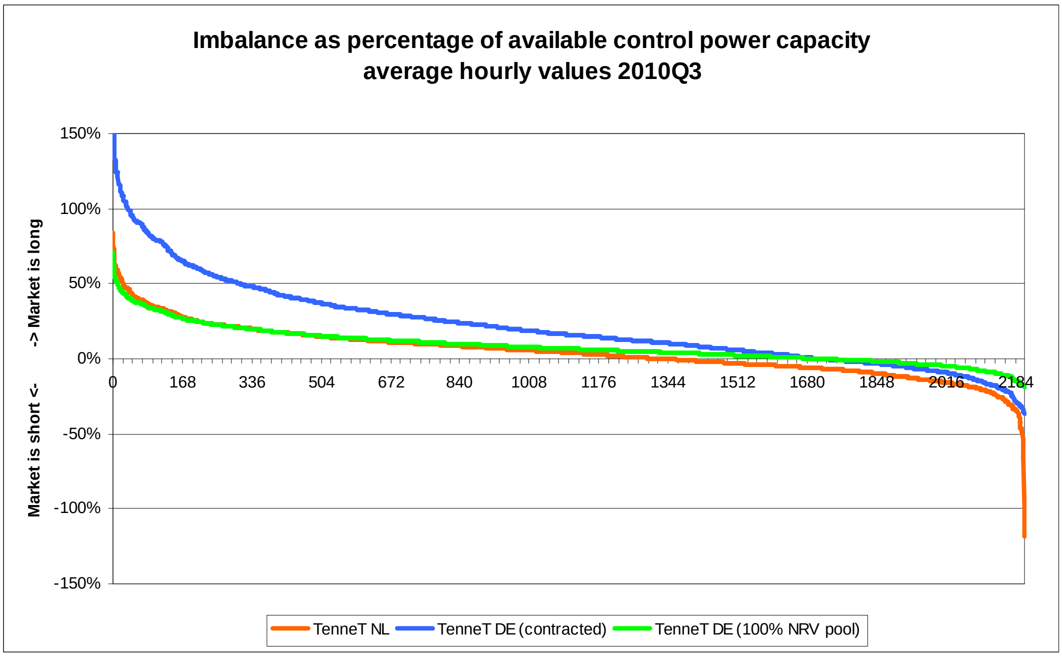

Figure 10 Imbalance as percentage of control power Q3

<u>Observations:</u>

- TenneT DE contracts more control capacity than TenneT NL.
- In the TenneT NL control area market parties offer a considerable amount of control power on top of the contracted capacity.
- The pooling of control capacity in Germany has led to lower contracted control capacity.
- Without the control capacity available in the pool, the relative imbalance compared to the available control capacity for TenneT DE is larger than for TenneT NL.

Market imbalance

In this section the market imbalances are calculated. The imbalances for the Dutch and the German CA must be comparable.

Therefore the market imbalance volumes for Q1 and Q3 of 2010 are calculated as absolute and net sums and are compared with the total planned CA infeed to correct for difference in CA size.

For TenneT DE the imbalance volumes that resulted from the difference between planned and realized renewables infeed and for the market excluding the renewables are also calculated.

Table 9 Imbalance figures NL & DE Q1 and Q3

Based on 15 min interval data	NL 2010Q1	DE 2010Q1	NL 2010Q3	DE 2010Q3
Total planned CA infeed [TWh]	25,6 100%	36,7 100%	28,3 100%	30,5 100%
Abs imbalance CA including renewables [TWh]	0,24 **1,0%**	1,11 **3,0%**	0,25 **0,9%**	1,08 **3,5%**
Net imbalance CA including renewables [TWh]	0,06 0,2%	-0,65 -1,8%	0,05 0,2%	0,82 2,7%
Abs imbalance renewables [TWh]	- -	0,57 1,6%	- -	0,85 2,8%
Net imbalance renewables [TWh]	- -	-0,36 -1,0%	- -	0,79 2,6%
Abs imbalance CA excluding renewables [TWh]	- -	0,84 **2,2%**	- -	0,64 **2,1%**
Net imbalance CA excluding renewables [TWh]	- -	-0,29 -0,8%	- -	0,03 0,1%

Figures 11 to 14 on the next page present the gross BUY and SELL imbalance positions of the BRPs and the resulting CA imbalance per PTU for Q1 and Q3 of 2010. They are presented at identical scale and ordered by CA imbalance.

Figures 15 to 18 on the subsequent page present the average (systematic) imbalance per PTU and the resulting average delta imbalance per hour.

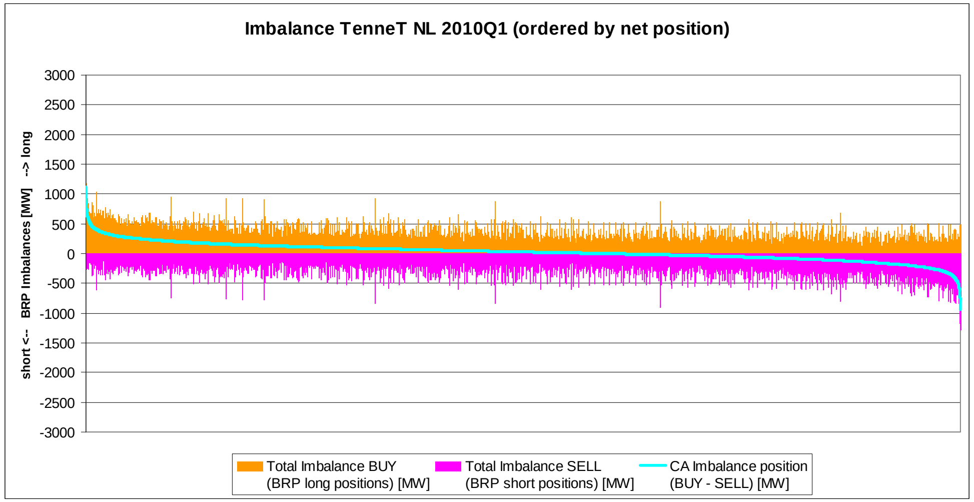

Figure 11 Imbalance TenneT NL Q1

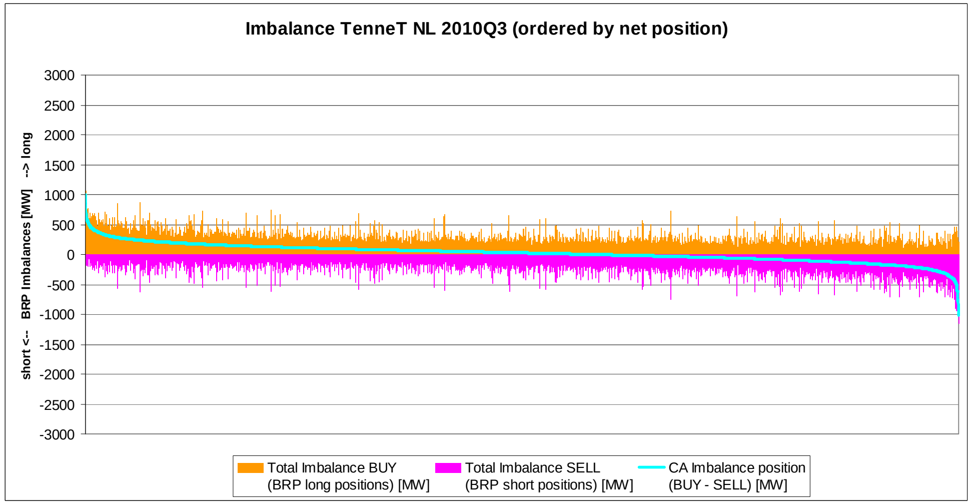

Figure 12 Imbalance TenneT NL Q3

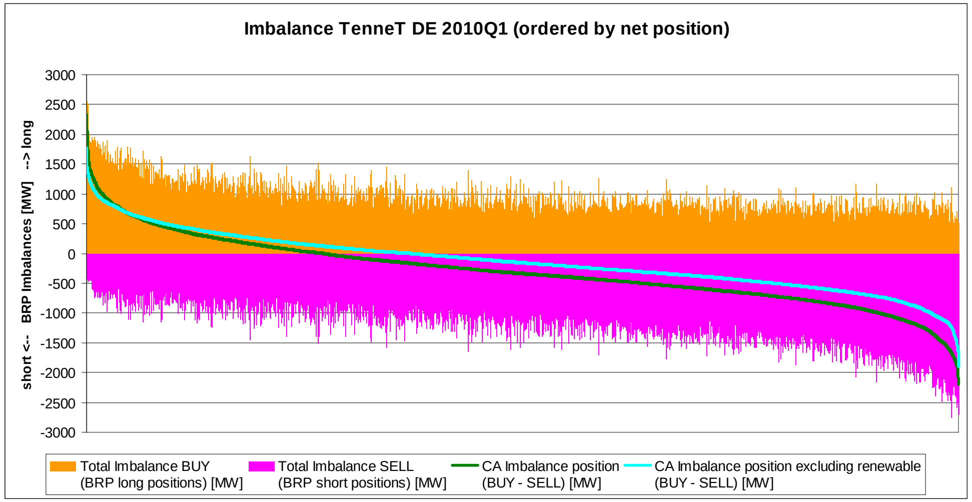

Figure 13 Imbalance TenneT DE Q1

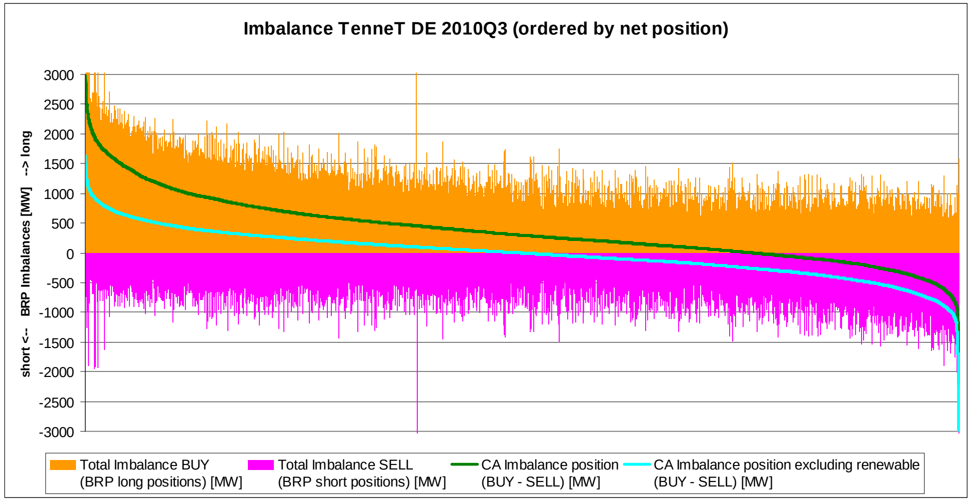

Figure 14 Imbalance TenneT DE Q2

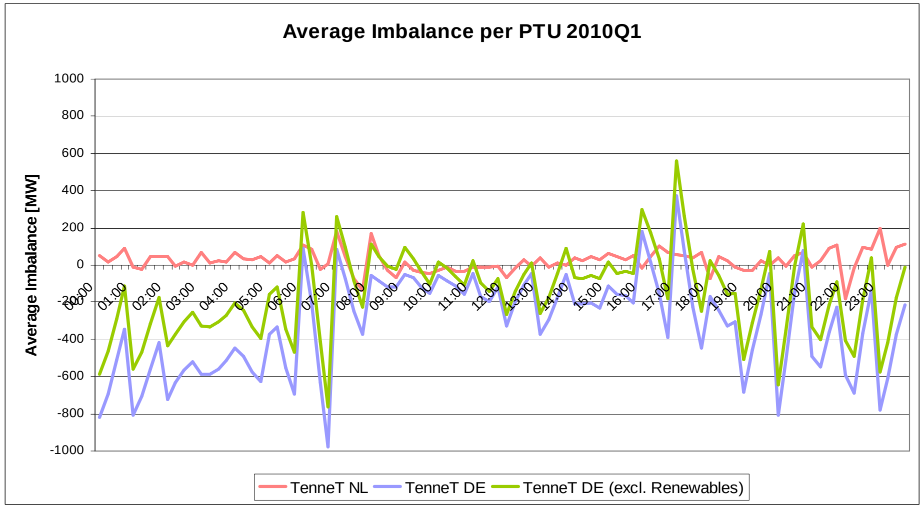

Figure 15 Average Imbalance per PTU TenneT NL Q1

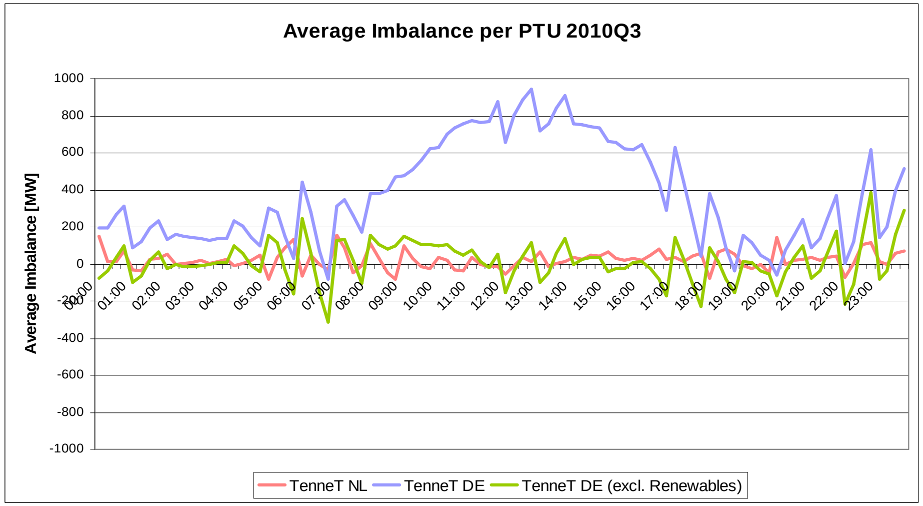

Figure 16 Average Imbalance per PTU TenneT NL Q3

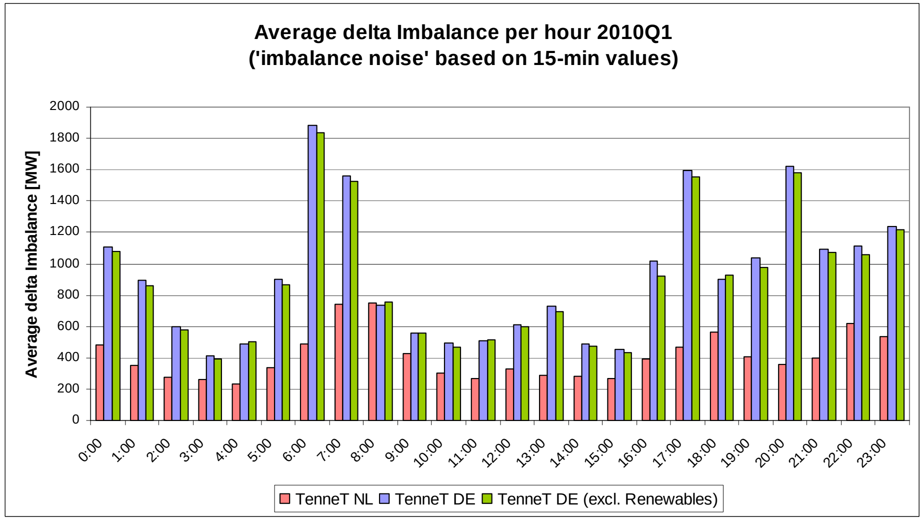

Figure 17 Average Imbalance per PTU TenneT DE Q1

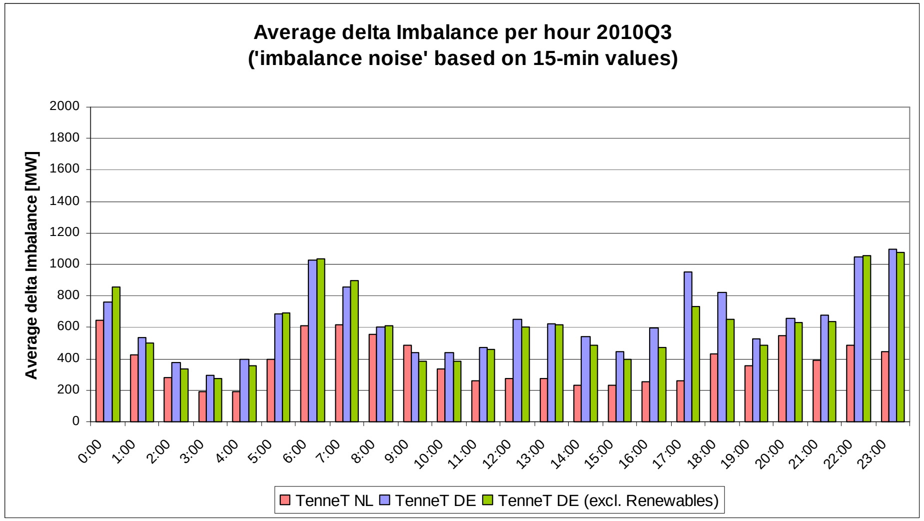

Figure 18 Average Imbalance per PTU TenneT DE Q3

Observations:

- The TenneT DE CA experiences more imbalance, both absolute and relative, than the TenneT NL CA.
- The average delta imbalance per hour is higher in the TenneT DE CA than in the TenneT NL CA, but noticeably improved in Q3. The hourly transition shifts in NL and DE are of relative comparable size in Q3.
- The above observations cannot be explained by the existence of a large share of renewables in Germany.

4.2 *Area Control Error (ACE)*

The ACE is an indicator for the remaining error after the TSO has acted to lower its control target. The ACE volumes for Q1 and Q3 of 2010 are calculated as absolute and net sums per PTU and are compared to the total planned CA infeed to correct for difference in CA size.

The 'noise' of the ACE is indicated by the Average delta ACE per hour. This indicator is the average of the absolute sum of delta ACEs per PTU per hour.

Table 10 Figures controller effectiveness

Based on 15 min interval data	NL 2010Q1	DE 2010Q1	NL 2010Q3	DE 2010Q3
Total planned CA infeed [TWh]	25,6 100%	36,8 100%	28,3 100%	30,5 100%
ABS sum Area Control Error [TWh]	0,11 **0,43%**	0,13 **0,36%**	0,11 **0,37%**	0,09 **0,29%**
NET sum Area Control Error [TWh]	0,01 0,05%	-0,04 -0,11%	-0,01 -0,02%	0,02 0,07%
Average delta ACE per hour [MW] 'noise'	300	261	290	192

Figures 19 to 22 on the next page present the requested control energy and the remaining ACE per PTU for Q1 and Q3 of 2010. They are presented at identical scale and ordered by CA imbalance.

Figures 23 to 26 on the next page present scatter diagrams with on the x-axis the CA imbalance and on the y-axis the remaining CA error per PTU.

Figures 27 and 28 on the next page present the average delta ACE per hour.

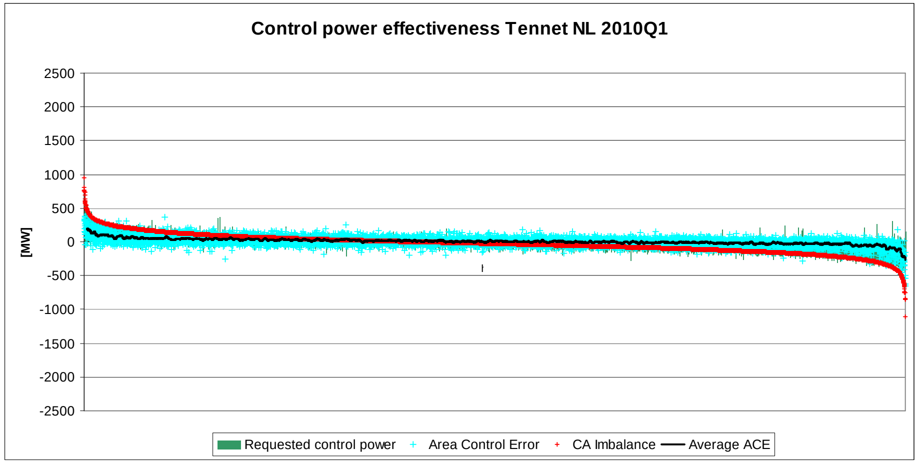

Figure 19 Controller effectiveness TenneT NL Q1

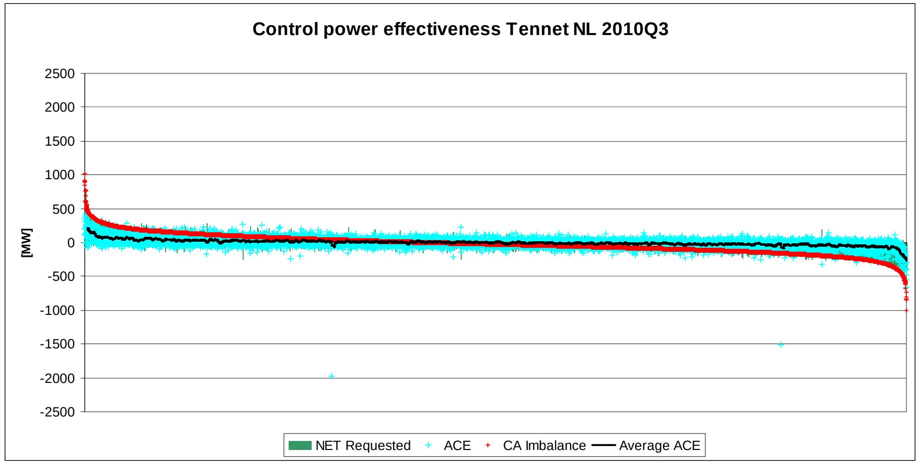

Figure 20 Controller effectiveness TenneT NL Q3

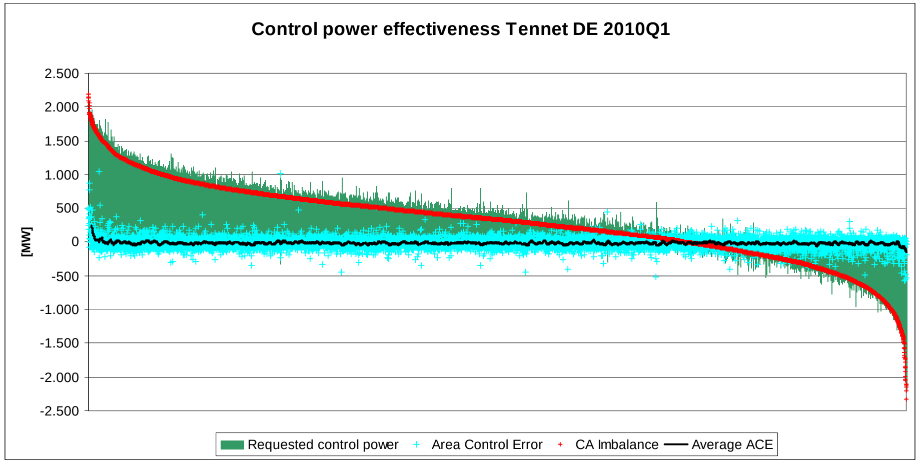

Figure 21 Controller effectiveness TenneT DE Q1

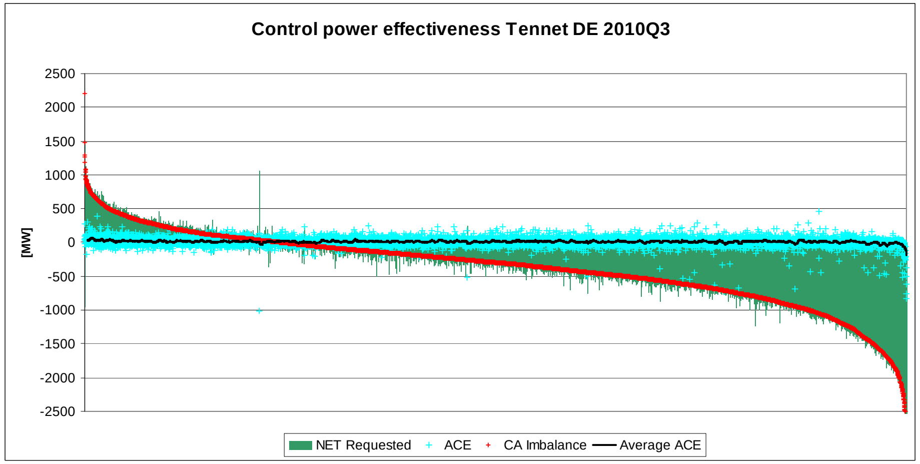

Figure 22 Controller effectiveness TenneT DE Q3

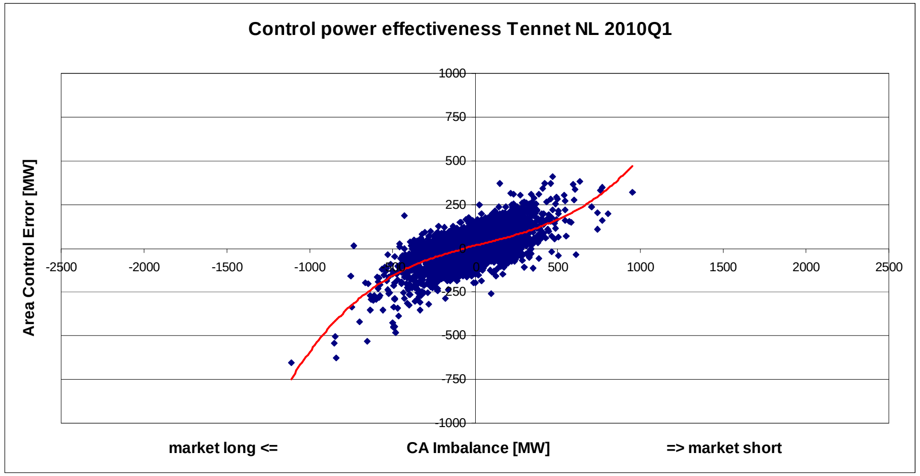

Figure 23 Control power effectiveness TenneT NL Q1

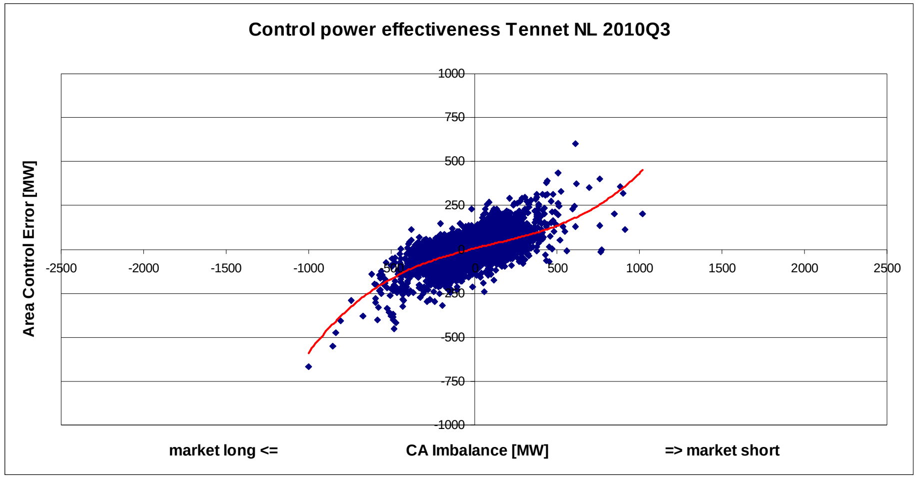

Figure 24 Control power effectiveness TenneT NL Q3

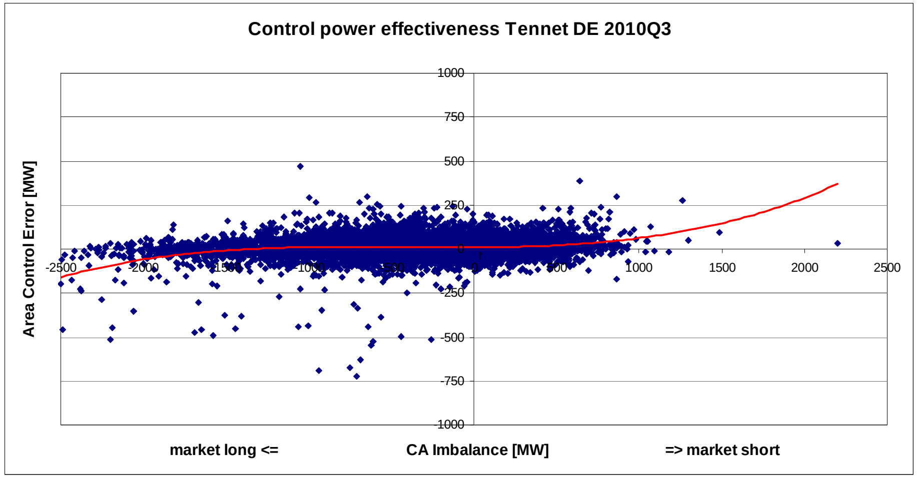

Figure 25 Control power effectiveness TenneT DE Q1

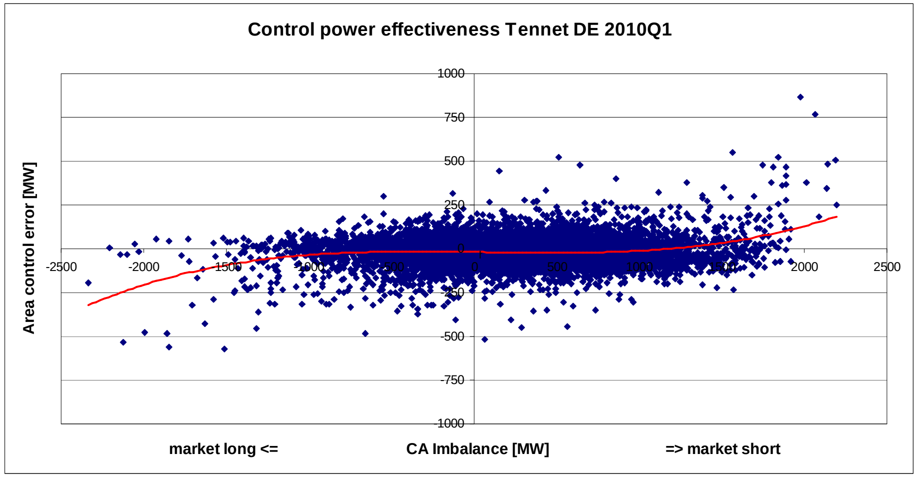

Figure 26 Control power effectiveness TenneT DE Q3

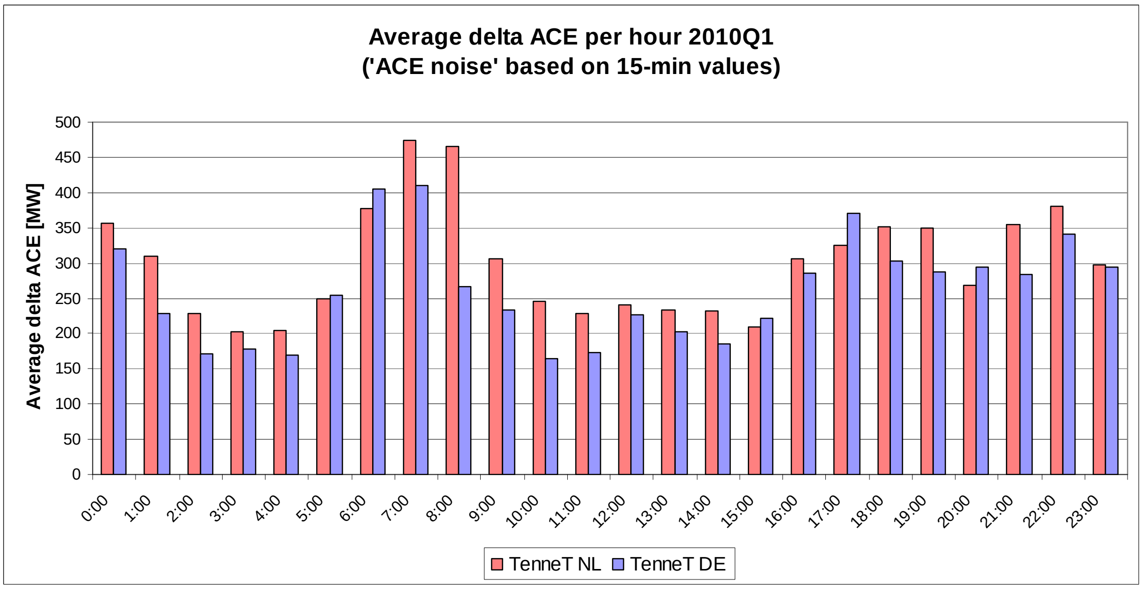

Figure 27 Average Delta area control error per hour in Q1

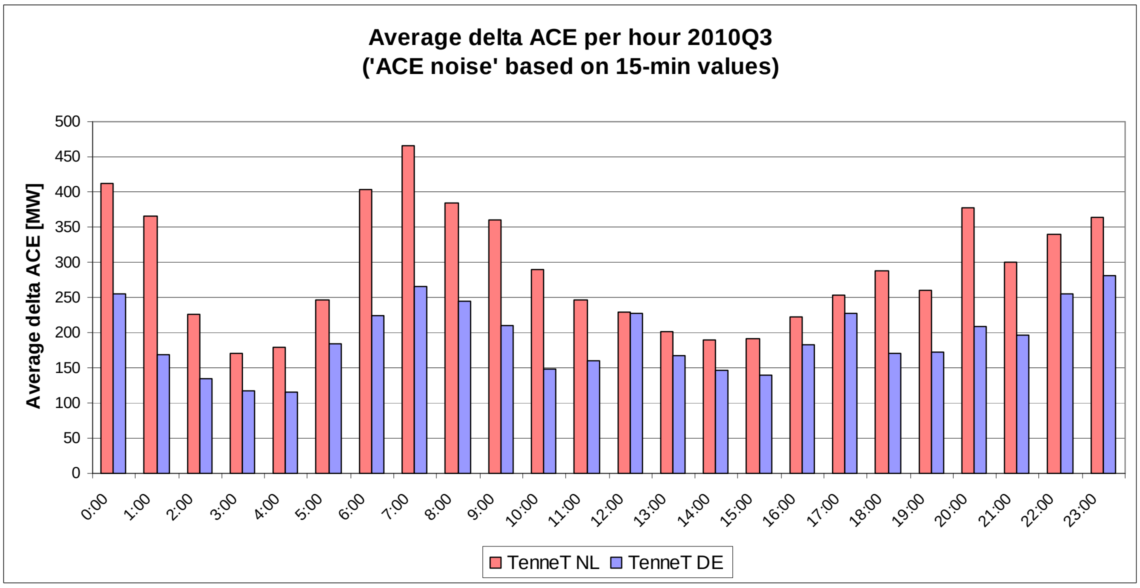

Figure 28 Average Delta area control error per hour in Q3

Observations:

- TenneT DE has to correct a larger volume of imbalance, but does so with a relatively lower ACE than TenneT NL.
- The absolute and relative ACE of TenneT DE improved in Q3

4.3 *Balance management costs*

To make financial a comparison between the TenneT NL and TenneT DE control areas, the costs for balance energy and control energy are presented as a delta price between the actual balance and control energy price and the day-ahead market price from the power exchanges (APX in NL, EEX in DE).

Table 11 Comparison of control and balancing energy costs

Based on 15 min interval data	NL 2010Q1	DE 2010Q1	NL 2010Q3	DE 2010Q3
Total planned CA infeed [TWh]	25,6 100%	36,8 100%	28,2 100%	30,5 100%
Total abs net imbalance [TWh]	0,24 1,0%	1,11 3,0%	0,25 0,9%	1,06 3,5%
Total abs net activated control [TWh]	0,19 0,8%	1,13 3,1%	0,20 0,7%	1,07 3,6%
Total abs net ACE [TWh]	0,11 0,4%	0,13 0,4%	0,11 0,4%	0,09 0,3%
Total abs gross activated control (including two sided) [TWh]	0,20 0,8%	1,25 3,4%	0,21 0,7%	1,18 3,9%
Average delta balance energy price [Euro/MWh]	38	57	29	35
Average delta control energy price [Euro/MWh]	31	60	27	45
Total delta balance energy costs [MEuro] (from BRP to TSO)	9	63	7	37
Total delta control energy costs [MEuro] (from TSO to PRD)	6	75	6	53

Table 12 Comparison of contracted control capacity

	NL 2010Q1	DE 2010Q1	NL 2010Q3	DE 2010Q3
Contracted capacity [MW]	UP 600 DN 300	UP 1594 DN 1205	UP 600 DN 300	UP 1733 DN 1349
Capacity costs [MEuro] (*) (estimates based on 2009 figures, costs per quarter)	17	43	17	47

(*) Capacity cost estimates are based on the Imbalance Management Comparative Study, March 2010.

Figures 29 to 32 show the control energy price distributions and their standard deviations as function of the requested control power volumes (MW). The right-hand Y-axis and the green distributions show the incidence of the requested control volumes per PTU.

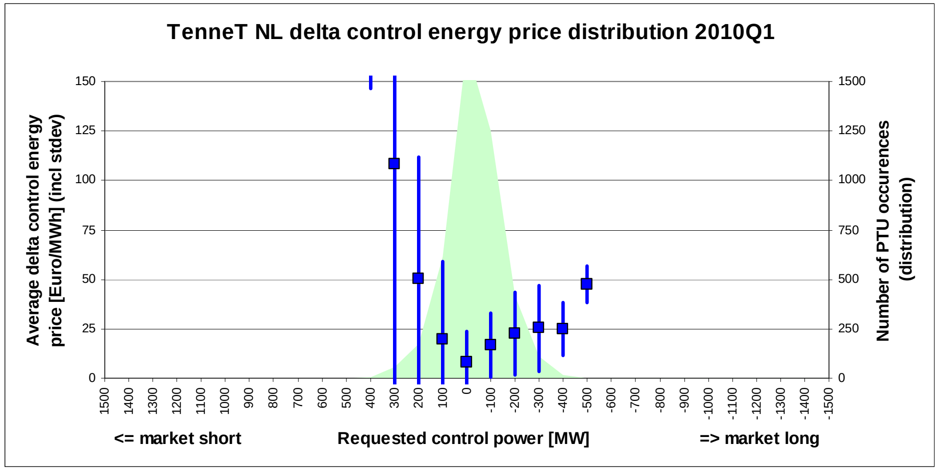

Figure 29 Control energy price distribution TenneT NL Q1

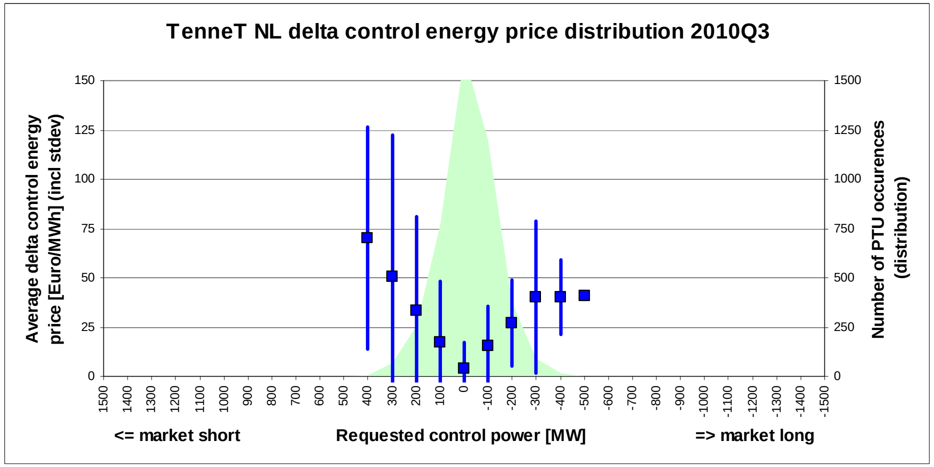

Figure 30 Control energy price distribution TenneT NL Q3

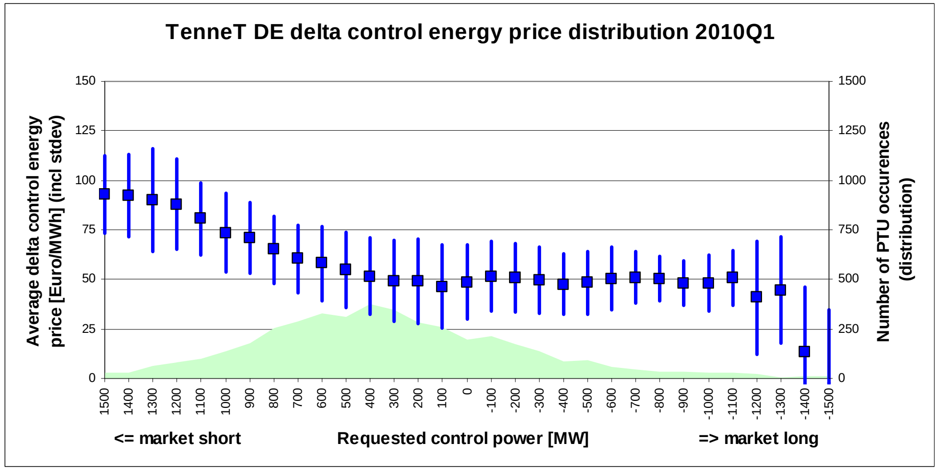

Figure 31 Control energy price distribution Tennet DE Q1

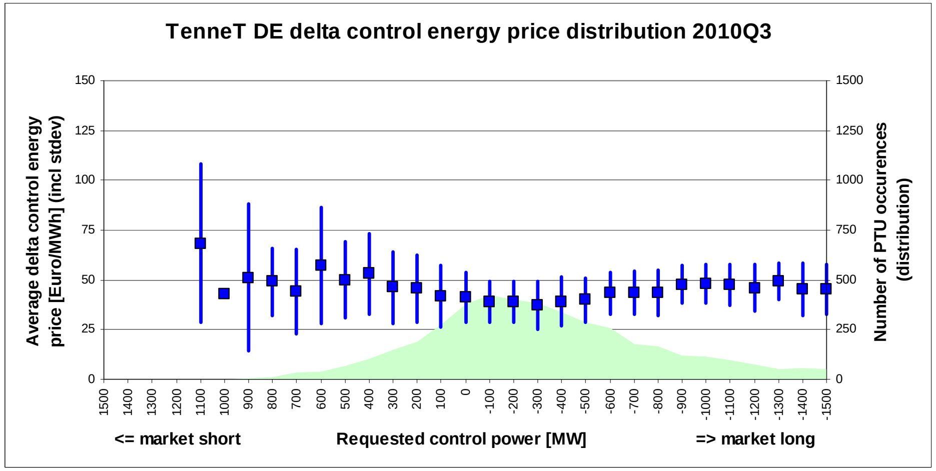

Figure 32 Control energy price distribution TenneT DE Q3

Observations:

- At TenneT DE the total imbalance and the total activated control energy is larger than in the TenneT NL area, but the resulting ACE is relatively smaller (especially in Q3).
- In both control areas the delta control energy price and the delta balance energy price is positive. Therefore the BRPs have an incentive to minimize imbalance, and producers have an incentive to offer control power products.
- In Germany the delta balance energy price is structurally lower than the delta control energy price. In the Netherlands this is the opposite.
- With small control energy volumes in Germany, the delta control energy price starts with 50 €/MWh. In the Netherlands the delta control energy price starts near 0 €/MWh.
- In the rare situations with maximum requested control energy volumes, the delta control energy price in the Netherlands is higher and more volatile than in Germany (marginal pricing vs pay-as-bid).
- As a result of both higher imbalance volumes and higher average delta imbalance energy price in Germany, the total delta balance energy costs are higher in Germany than in the Netherlands.
- The same observation applies to the total delta control energy costs.
- In the TenneT DE control area, the contracted capacity costs are higher than in the TenneT NL control area.

5 Conclusions and recommendations

5.1 *Conclusions*

1) Imbalance volume

Market parties create a lower imbalance volume in NL than in DE.

- ➢ The renewable energy contribution cannot explain the higher imbalance in DE (based on analysis).
- ➢ The most likely explanation for this is the active deviation from planned in-feed / off-take by BRPs that economically optimize their position:
  - o In NL real-time feedback by the TSO on actual market balance position and imbalance price enables BRPs to act on opportunities to arbitrage between imbalance price and their own marginal production price resulting in a reduction of the system imbalance (the marginal price for control energy determines the actual balance energy price for this passive control).
  - o In DE the price difference between imbalance energy (average price) and the control energy (pay-as-bid) creates opportunities for control power suppliers to arbitrage between both by creating additional system imbalance.

2) Balance management costs

The relative balance management costs in NL are lower than in DE.

- Lower initial imbalances;
- Less requested control energy in NL;
- Lower average delta control energy price in NL;
- Less contracted control capacity in NL;
- Comparable capacity price in NL and DE.

- ➢ In NL the control energy bidding system is more flexible. All pre-qualified parties can offer additional control energy bids, also when the capacity is not contracted. Up to one hour before delivery the price of the control energy bids can be adjusted. After that they become firm. This increases the number of bids and the competition on control energy prices. Bid prices can vary per PTU.

3) Controller effectiveness / robustness

TenneT DE has a system that allows for higher input (imbalance) volatility. The resulting averages ACE values are comparable for TenneT NL and TenneT DE. However the initial imbalance is considerably higher in Germany.

- ➢ The operating practice of TenneT DE and TenneT NL differ, perhaps because of different control quality standards used in the Netherlands and Germany.

The robustness in terms of imbalance occurrence as fraction of the available control capacity is comparable for TenneT DE and TenneT NL.

The hourly transition shifts are an inherent part of both systems and are of comparable size:

- ➢ They happen mainly in the morning and evening when the power demand is continuous increasing or decreasing, while power production plans are hourly based (marketable blocks). Delivering the difference as control energy is more attractive for the producers than arbitraging on planned energy profits. To reduce the effect of the hour transition shifts the tradable blocks interval on the day-ahead markets should be changed from hours into 15 minutes.

5.2 *Recommendations*

2) Reduce control energy costs by introducing more flexibility and competition in the bidding process in DE

- Accept control energy bids of pre-qualified parties that are not part of the contracted capacity.
- Introduce more flexibility in bid pricing (allow changes up to 1 hour to delivery, prices per PTU).

2) Reduce imbalance of market parties in DE

- Educate BRPs about the benefits and importance of reducing imbalance
- Re-evaluate the incentives:
    - Enable reduction of system imbalance using passive contribution of BRPs by considering to share more real-time system balance and balance energy price information with the market.
    - Prevent creation of additional imbalance by arbitrage opportunities of control energy suppliers by considering marginal control energy pricing.

6 Appendix

The datasheets provided by TenneT DE included the following columns with complete time series for Quarters 1 and 3 of the year 2010

DATE	TIME (start of PTU)	Generation (Control Area)	Power Exchange Price (day ahead)	Imbalance Price SELL (TSO sell to BRP)	Imbalance Price BUY (TSO buy from BRP)	Control Power Price UP (DE weighted average price)	Control Power Price DOWN (DE weighted average price)
yyyy-mm-dd	hh:mm		[EUR/MWh]	[EUR/MWh]	[EUR/MWh]	[EUR/MWh]	[EUR/MWh]

DATE	TIME (start of PTU)	Available Control Power Capacity UP	Available Control Power Capacity DOWN	Available Control Power Capacity UP	Available Control Power Capacity DOWN	Available Control Power Capacity UP	Available Control Power Capacity DOWN		Available Control Power Capacity UP	Available Control Power Capacity DOWN	Available Control Power Capacity UP	Available Control Power Capacity DOWN	Available Control Power Capacity UP	Available Control Power Capacity DOWN
yyyy-mm-dd	hh:mm	[MW] NRV SCR + TCR	[MW] NRV SCR + TCR	[MW] NRV SCR	[MW] NRV SCR	[MW] NRV TCR	[MW] NRV TCR		[MW] TPS SCR + TCR	[MW] TPS SCR + TCR	[MW] TPS SCR	[MW] TPS SCR	[MW] TPS TCR	[MW] TPS TCR

DATE	TIME (start of PTU)	Called Control Energy UP	Called Control Energy DOWN	Net Called Control Energy CA (UP - DOWN)	Total Imbalance BUY (sum of individual BRP long positions)	Total Imbalance SELL (sum of individual BRP short positions)	Net Imbalance position CA (SELL-BUY)	ACE (remaining net control error per PTU)	*ACE calculated*	Planned CA infeed (sum of all BRP programmed infeed)	Planned renewable energy infeed TenneT DE	Realised renewable energy infeed TenneT DE	Imbalance TenneT DE
yyyy-mm-dd	hh:mm	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	*[kWh]*	[kWh]	[kWh]	[kWh]	[kWh]

The datasheets provided by TenneT NL included the following columns with complete time series for Quarters 1 and 3 of the year 2010

DATE	TIME (start of PTU)	Power Exchange Price (day ahead)	Imbalance Price SELL (TSO sell to BRP)	Imbalance Price BUY (TSO buy from BRP)
yyyy-mm-dd	hh:mm	[EUR/MWh]	[EUR/MWh]	[EUR/MWh]

DATE	TIME (start of PTU)	Available Control Power Capacity UP (afroep)	Available Control Power Capacity UP (FVR)	Available Control Power Capacity DOWN (afroep)	Available Control Power Capacity DOWN (FVR)
yyyy-mm-dd	hh:mm	[MW]	[MW]	[MW]	[MW]

DATE	TIME (start of PTU)	Called Control Energy UP (other)	Called Control Energy UP (FVR)	Emergency power (UP)	Called Control Energy DOWN (other)	Called Control Energy DOWN (FVR)	Net Called Control Energy CA (UP - DOWN)	Total Imbalance BUY (sum of individual BRP positions, buy from BRP)	Total Imbalance SELL (sum of individual BRP positions, sell to BRP)	Net Imbalance position CA (BUY - SELL)	ACE (remaining net control error per PTU)	Planned CA infeed (sum of all BRP programmed infeed)
yyyy-mm-dd	hh:mm	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]	[kWh]