Development of the imbalance of the Dutch electricity grid

The impact of high shares of wind and solar generation on imbalance management

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1. ABSTRACT

Generation and consumption within an electricity grid have to be in balance to keep the grids´ frequency at 50 Hertz. As a result, consumption is forecasted for which generation is scheduled. Deviations from the scheduled generation and consumption are referred to as imbalance and have to be settled in real time. Intermittent generation is expected to have an impact on the grids balance as their generation can only be predicted with limited certainty. The amount of installed capacity of intermittent generation such as wind and solar energy is expected to increase in the near future. In some countries in Europe the amount of installed capacity wind and solar generation has rapidly increased in recent years. An increase in imbalance will result in a bigger market for settlement mechanisms such as smart grids. Increased balancing costs will result in a bigger incentive for demand response (DR) as a balancing mechanism.

With the increase of installed wind and solar generating capacity, it is found that the imbalance volume in Spain and Germany has increased in recent years. The imbalance volume has increased by amounts which can still be settled with control power activation. It is found that the share of the installed wind and solar capacity of the total installed capacity has a turning point in which an increased imbalance is noticeable. For this, the imbalance share of total consumption is taken as a measure in order to compare different sizes of control area and their imbalance. It is found that the turning point is at 20% of the installed wind and solar generating capacity. When more wind and solar generation is installed, the imbalance share increases as well and results in high shares of imbalance. However, below 20% installed capacity not a noticeable effect on the imbalance volume due to wind and solar generation is found.

Since this increased share of imbalance found which is mostly noticeable in Germany, an increase of activated control power is expected to settle imbalance. However, due to the cooperation of the German Transmission System Operators (TSOs) the amount of activated control power has decreased. The German TSOs have been cooperating since 2008 when the Grid Control Cooperation (GCC) was implemented. The GCC provides the opportunity for TSOs to settle imbalance in their control area with imbalance in the opposite direction with another control area. This results in less control power activation for both control areas as they settle imbalance with each other if possible. As a result the amount of activated control power has decreased after implementation of the GCC and therefore the prices which have increased with the increase of control power activation decreased.

The GCC has transformed into the International Grid Control Cooperation (IGCC) when neighboring countries of Germany were implemented as well. The Netherlands started participating in February 2012. Same as for the German TSOs, the imbalance could be settled with the interconnections for a large part. Only 55% of the current imbalance volume has to be settled with control power from which most of the rest is settled with interconnections through the IGCC. This has resulted in a decreased market for balancing settlement mechanisms like Demand Response (DR). With an expected increase in imbalance volume, DR was expected to play a big part in the settlement process. Since the IGCC has decreased the need for balancing settlement this market has decreased and therefore the need DR for balancing purposes has decreased.

Within this research an estimation of DR potential in households for balancing purposes has been investigated. Only a limited number of devices in households are suitable for balancing purposes but together this results in a large balancing power potential. All the households in the Netherlands

combined can provide balancing power for the largest share of the current imbalance. When the need for balancing power increases, DR in households will be able to settle a large part of the imbalance. With recent technology, throughout the year more than 100 MW of down regulation and 200 MW up regulating potential is available. For the near future this is however highly unlikely as the control power has decrease and might decrease more when more countries participate in the IGCC. Since the balancing costs have to go up before DR will be economically feasible.

2. LIST OF ABBREVIATIONS

BRP: Balance Responsible Parties

DG: Distributed Generation

DR: Demand Response

DSM: Demand Side Management

GCC: German Grid Control Cooperation

GTC: Gate Closure Time

IG: Intermittent generation

IGCC: International Grid Control Cooperation

OTC: Over The Counter

PACE: Processed Area Control Error

PTU: Program Time Unit

RES: Renewable energy sources

TSO: Transmission System Operator

VRES: Variable Renewable Energy Sources

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4. INTRODUCTION

Energy is an important part of daily life and energy availability is seen as an important part of both economic and social wellbeing (Ramirez, 2012). An electricity grid is necessary in order to distribute energy, the electricity grid is a complex system which has to be stabilized in order to prevent black outs. The Dutch grid has proven to be very stable and reliable since long black outs do not occur often. This might change however when more variable renewable energy sources (VRES) will be implemented. For the future of energy reliability, it is necessary to conduct research on the impact of large scale implementation of VRES in the grid. VRES are expected to have an impact on the grids balance. Imbalance occurs when there is a difference between planned generation and consumption and actual generation and consumption in the control area. This is an important part of the implementation of intermittent generation (IG) like solar and wind energy.

The current electricity grid is designed with central generation after which electricity is transmitted and distributed to the consumer. In order to keep the grid stable, generation should always meet demand (including losses) as there is no intrinsic storage capacity in the grid. This is done by Balance Responsible Parties (BRP) which provide energy programs a day ahead to the Transmission System Operator (TSO). Energy programs are estimations about the electricity consumption and generation for the next day in the control area of the BRP. A BRP manages the demand and generation within its control area and is obliged to keep this balance. There are several BRPs which all have to account to the TSO, the TSO will combine all the energy programs from the BRPs and will balance the sum of all deviations of the energy programs combined which is measured by frequency deviations.

Since the energy program is an estimation, there will be a mismatch in generation and consumption because of fluctuating consumer behavior and generation differences. This mismatch is called the imbalance and has to be settled by controls in real-time. Imbalance is found for the individual BRPs which results in a penalty and imbalance for the TSO which is the sum of all imbalances in the control area of the TSO. The imbalance for the BRP is an economic and administrative issue which gives an incentive for the BRPs to keep their control area in balance. The sum of the imbalance of all BRPs in the control area of the TSOs has to be settled by the TSO which is Tennet in the Netherlands.

Imbalance settlement is a technological issue which is done in order to keep the frequency of the grid at 50 hertz. The imbalance has to be minimized as it leads to large expenditures and can harm the reliability of the grid (Tennet). Causes of imbalance are failure of power plants, inaccuracy in generation and forecasting errors of generation or consumption (Frunt J. , 2011). With conventional resources, generation can be controlled quite accurately leaving consumption forecast deviations as the main imbalance cause. Generation management is however, more difficult for VRES which are usually dependent on local weather conditions.

As it is expected that more VRES will be installed in the electricity grid looking at the current trends, it is necessary to gain a good understanding of the influence of VRES on the imbalance of the grid (Schleicher-Tappeser, 2012). For the reliability of the grid it would be helpful to know the impact of large shares of VRES implemented in the grid without knowing its impact. For successful implementation of large shares of VRES more research needs to be done on the impact of VRES on the imbalance, especially since system operators are becoming concerned about the upcoming effects (Milligan).

Flexibility can be a possibility to solve issues regarding the imbalance; this can be done with Demand Response (DR). With DR, consumption is influenced to help demand meet supply, while currently mostly generation is managed in order to meet demand. DR can be very useful when much generation from VRES appears and less is consumed. On the other hand, it can also help lower the demand when less electricity is generated. If the imbalance volume will increase in the future, this will create a big market for DR since imbalance is expensive to settle. It is, however, not clear how the imbalance market will change.

5. RESEARCH QUESTION AND SCOPE

In this research, the German and Spanish imbalance market will be studied to find the impact of VRES on the grid. These markets are chosen because of the high shares of VRES in these countries which will provide an insight in the impact of VRES on grid balancing. This research focuses on the effect of VRES on the imbalance as a whole and will therefore compare both the technical situation as well as the regulations in these different countries. It can be found that different regulations have a big impact on the imbalance market (Hakvoort, 2009). The impact of these different regulations will first be examined thoroughly. Within this research, wind and solar energy will be studied as the actual generation of these technologies can be predicted only with limited certainty. The amount of installed capacity of these two technologies is therefore of most importance because the actual generation of these energy sources will deviate from predicted generation. An increase of imbalance is expected which will result in an increased market of imbalance settlement. This can be provided by Smart Grids which settle imbalance automatically with Demand Response (DR) of smart appliances. DR can be used to influence the demand for different economic reasons when prices are variable, to facilitate decentralized generation and accommodate local energy surplus, shortages and storage (KEMA, 2012).

General question of this study is: *How will the balance and imbalance settlement of the Dutch grid change with high share of wind and solar generation?*

To answer this question, some sub questions need to be answered as well.

- *What is the characterization of the market to settle the imbalance in the Netherlands, Germany and Spain in order to make a comparison?*
- *How has the increase of VRES influenced the imbalance in volume and price of the German and Spanish market?*
- *How will the potential market for ancillary services change with high shares of VRES in the Netherlands?*
- *What is the potential capacity of demand response in households for balancing purposes?*
- *How will the potential market for Demand Response for balancing purposes change?*

At the start of this research imbalance was thought to increase and therefore result in an increased market for DR in households. This has also been investigated.

The scope of this research is limited to Germany, Spain and the Netherlands. These markets will be examined and compared with each other, in order to find the impact that VRES can have in on the imbalance in the Netherlands. Historical data of imbalance volume and price will provide insight in the changes due to the installation of more VRES in Germany and Spain.

The implementation of electricity storage is not included in this research. It is often mentioned as a solution for fluctuation if load can be stored at high speed. For this research this will not be included to explore the possibilities of high shares of RES together with DR without storage facilities.

The focus for renewable electricity generation will be on wind and solar generation. The generation output of these technologies can only be predicted with limited certainty which is expected to result in imbalance. Since the installed capacity in the Netherlands of wind and solar generation is expected to increase in the Netherlands the impact on the imbalance is interesting for the Dutch market (Schleicher-Tappeser, 2012).

The focus of DR will be on households, this means that Smart Grids would be introduced which can be used to influence the demand. DR of industrial demand will not be included. Appliances in households will be managed to influence the energy demand without any decrease of the comfort of living.

To settle imbalance the most important control power is secondary control power. Besides secondary control power, tertiary control power is an important imbalance settlement energy as well. Primary control power however is only used for frequency containment and provides no insight in the imbalance volume settlement. Primary control power is therefore left out of scope for this research.

6. METHODOLOGY

For a thorough comparison of the impact of VRES, the markets of the countries have to be compared. The regulations of the imbalance settlement of the included markets have to be understood. The regulations are available by government websites and scientific papers of market comparisons are available. Literature research shall be done to find the differences and similarities.

After the imbalance settlement mechanisms are studied, data of the actual imbalance will be analyzed. The markets will be characterized by data analysis of the imbalance volume, settlement prices and volumes of activated control power. This data will provide an insight in the changes in the market in Germany, Spain and the Netherlands together with their impact on the imbalance.

Indicators to compare the imbalance are:

- Volume of the system imbalance (MW)
- Volume of activated control power (MW)
- Balancing cost (€/MWh)

As generation from VRES will fluctuate and can only be estimated, it is assumed that flexible demand can solve the inaccuracy in predicted generation. The impact of DR on the imbalance market has to be estimated. To find the impact it can have, first literature research will be done. This will make it possible to find the potential of DR in households. To find the potential, first the appliances which are suited for balancing purposes with DR are found. The potential of these appliances in households in the Netherlands will be calculated in order to find if an increase of imbalance can be settled with DR.

LITERATURE REVIEW

A wide range of literature has been studied which ranged from scientific literature to company documents. A lot of research has been done on the implementation of wind energy into the electricity grid. Already from the 1980's researchers have published papers on this topic. For the implementation of solar generation less academic literature is found as it only started to become interesting due to the large amount of installed solar generation in Germany. Also literature from companies is studied. Due to the increase of the amount of wind and solar generation, the impact it has is interesting for a lot of parties involved in the electricity sector. All literature is compared with each other in order to find the similarities and differences. As the topics have recently become increasingly interesting, more universities started to research this topic. Contact has been made with researchers from different institutes which has led to the exchange of information. Technical information is found from scientific papers, textbooks and data made available by reliable international institutes.

DATA ANALYSIS

Data of the imbalance is made available by the TSOs which is published on their websites. The data freely available and information about imbalance settlement is published by the TSOs. Since a lot of data is available, it should be handled with care. The definitions are very important and some data relies on measurements while other data is done by assumptions. This makes that a good understanding of the data is needed before actual conclusions can be made. Between countries different expressions are used which makes that a good understanding of the market is necessary for a good interpretation.

Since the data is made available on a quarterly hour basis for Germany and the Netherlands and on an hourly basis for Spain, a lot of data is found for several years. In order to get a good impression, the monthly average is taken for the time frame of the country. All data used in this research is publically available or can be purchased by institutions.

7. COUNTRIES IN EUROPE WITH WIND AND SOLAR GNERATION

For this research, countries with a reasonable share of intermittent generation are needed. Therefore the countries in Europe together with their installed capacity wind and solar generation are found.

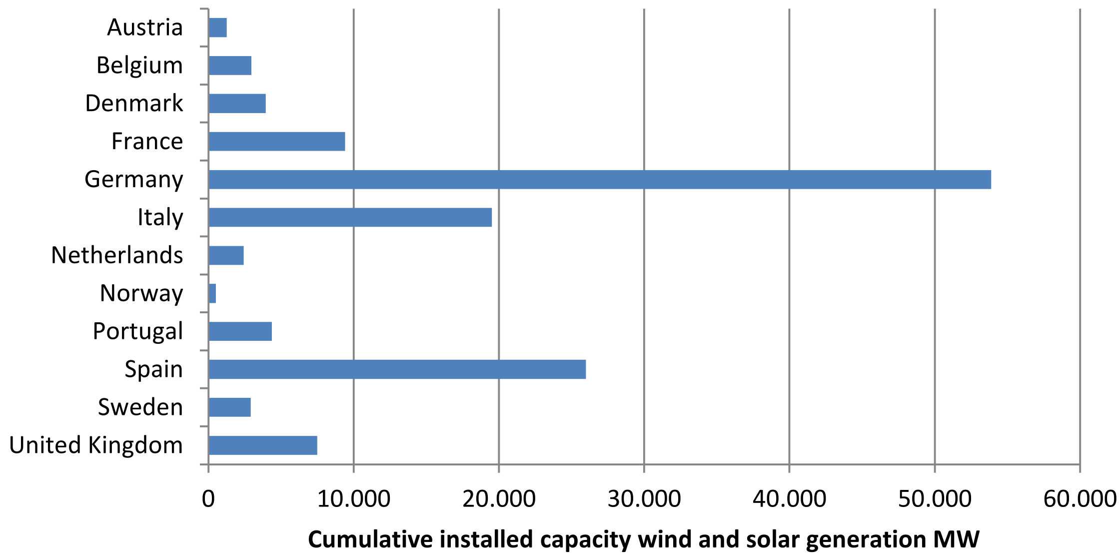


FIGURE 1 : INSTALLED CAPACITY WIND AND SOLAR GENERATION BY COUNTRY IN EUROPE IN 2011 (BP, 2012)

Figure 1 shows the amount of installed capacity wind and solar for several countries in Europe. Since the impact of wind and solar generation will be studied, countries with a lot of installed wind and solar generation are preferred. Germany, Spain and Italy clearly have more installed capacity than the other European countries and are therefore interesting countries to study. To compare markets it is also necessary that the regulations show a resemblance as changes can result in different outcomes in grid balance. Since the markets of Denmark, Spain and Germany show many similarities, these countries are chosen to study. The rapid development of installed solar capacity in Germany provides an insight in the impact of distributed generation since the quick adjustment of the grid balancing is needed and therefore the impact is expected to be noticeable.

DATA AVAILABILITY

The data needed to study the imbalance market is published on the websites of the TSOs and is therefore limited by the amount of data preserved. Some data is only available from recent years, while other data has proven to be unreliable. This makes the possibility of studying the effect of VRES on the grid limited and for some countries it is hard to make conclusions.

In Denmark the amount of data available is a limited, only reliable imbalance data from the East side of the country from 2001 – 2008 is preserved. Unfortunately during this time, almost no additional VRES has been installed. That is why, after it was found that not enough data is available, Denmark has been excluded from this research. For Germany only two of the four TSOs have preserved enough data for proper analysis, these are Tennet and 50 Hertz. The other two TSOs have not preserved enough data for this research. Therefore the analysis has focused on these two TSOs in Germany and on the Spanish TSO Red Electrica. Only for a complete view of the imbalance market, data of other TSOs is used as well for one analysis.

GERMANY

In the last decade a lot of wind and solar power has been installed in Germany. From 2001 – 2011 the installed capacity of solar energy in Germany has gone from 186 MW – 2.4820 MW and for wind this has gone from 8.750 MW – 2.9075 MW installed (BP, 2012).

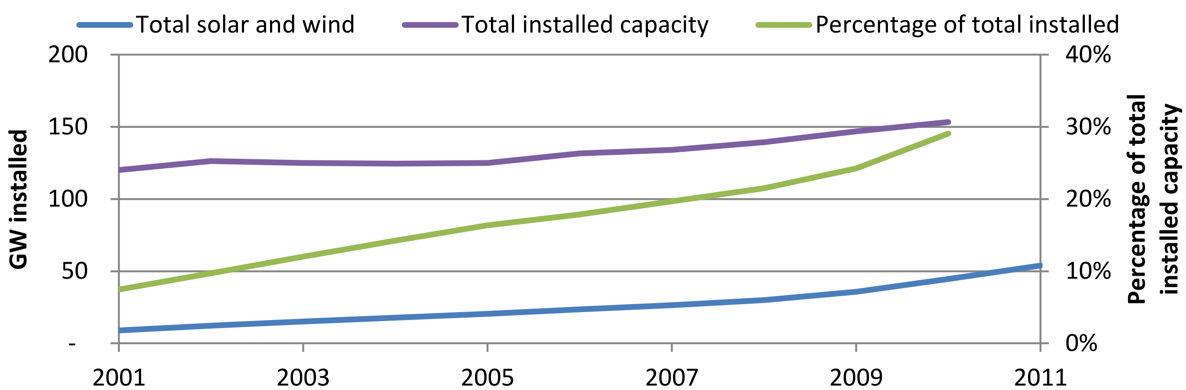
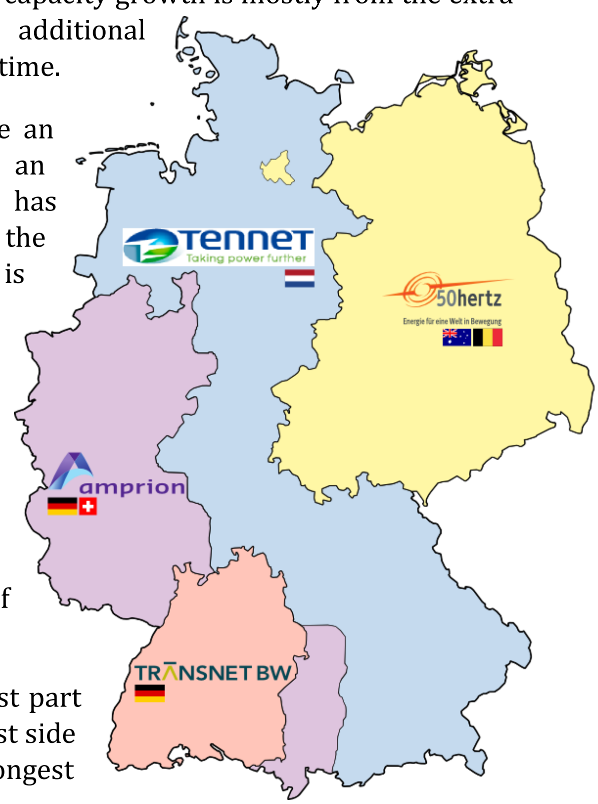


FIGURE 2: INSTALLED ELECTRICAL CAPACITY IN GERMANY (EIA, 2012) (BP, 2012)

In Figure 2 it can be seen that the total installed electricity capacity growth is mostly from the extra installed wind and solar generation. So almost no additional conventional power plants have been installed during this time.



The large increase in share of VRES is expected to have an impact on the grids imbalance. This makes that it is an interesting case to study how the imbalance market has evolved. The control area balance which is published on the website of the four TSOs which makes that enough data is available. 'The control area balance is the sum of all variations occurring in the respective balancing groups between the declared schedules, on the one hand, and actual customer usage and actual feed-in by power generators, on the other' (50Hertz). Since there are four TSOs in Germany, they have been analyzed separately with the share of solar and wind in their control area. This way, four separate cases can be studied which all have the same market regulations but with different amounts of VREs installed.

The German market was fully liberalized in 1998. The east part of Germany is mostly controlled by 50 Hertz while the West side is controlled by Amprion and Transnet. The central and longest control area is controlled by Tennet. In 2010 the Dutch TSO Tennet bought the TSO Transgas from E.On which is thought to result in synergy savings between the operators. The amount of wind and solar energy per control area varies per TSO same as the consumption.

In the last five years the amount of solar generation has increased rapidly, leading to almost the same amount of wind generation. Since solar power is usually installed on the rooftop of households, this is not managed by the BRPs which will learn throughout the year that solar panels are installed. The TSOs Tennet and 50 Hertz which are used for this research have the highest shares of wind and solar generation in their control area leading up to 40% of the total installed capacity.

SPAIN

For Spain the same data is available on the website of the Spanish TSO Red Electrica de Espana which is the only TSO in Spain. In Figure 3 the amount of wind and solar generation installed capacity together with the total installed capacity is shown. In 2010 more than 24% of the total installed capacity in Spain was wind and solar energy. The total installed capacity wind energy has gone from 3.522 - 21.726 MW in between 2001 – 2011 while for the solar installed capacity went from 4 – 4.270 MW. In the last years the increase of installed capacity wind and solar generation declined, this is most likely the result of the economic crisis in Europe.

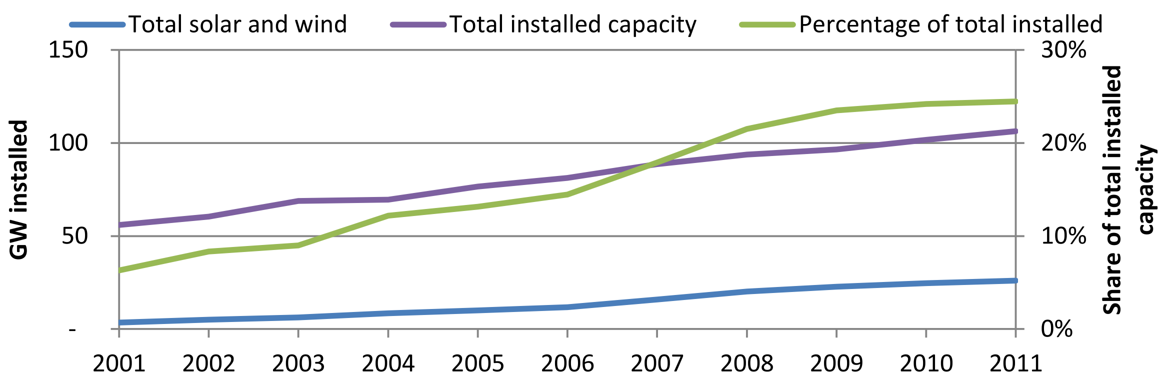


FIGURE 3: INSTALLED ELECTRICAL CAPACITY IN SPAIN (EIA, 2012) (BP, 2012)

Similar as for Germany, the imbalance volume provided by the TSO can be studied. Data about the imbalance is made available by the TSO from 2007 onwards.

THE NETHERLANDS

The amount of installed wind and solar energy is a lot less than in Germany and Spain but is expected to increase. In 2011 the amount of wind and solar installed capacity of the total was 8,8%. As the prices of solar panels have decreased rapidly and the goals for 16% of renewable energy in 2020 this is expected to change.

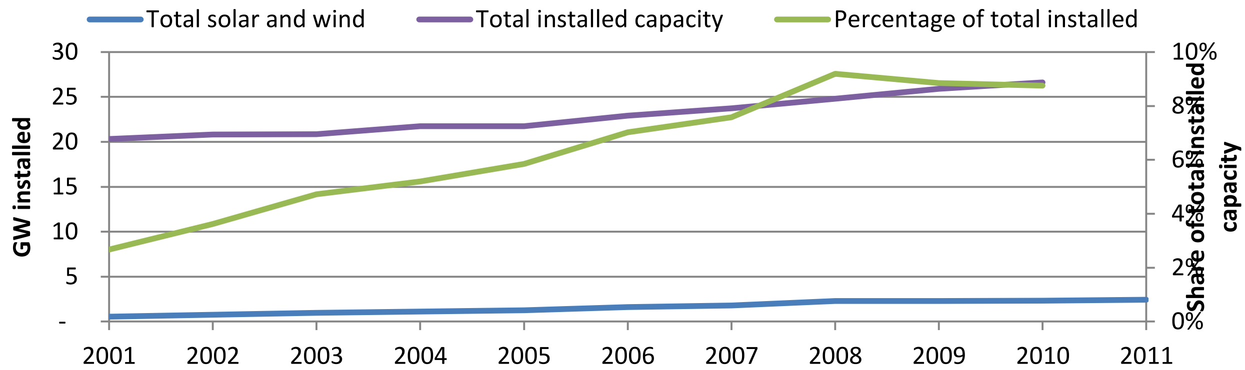


FIGURE 4: INSTALLED ELECTRICAL CAPACITY IN THE NETHERLANDS (EIA, 2012) (BP, 2012)

The decrease in the percentage of the total installed capacity is due to an increase in installed capacity of conventional power plants. The actual amount of installed capacity wind and solar has actually increased during these years, but the share has decrease.

8. IMBALANCE MANAGEMENT

CONTROL AREA BALANCE

As a measure for the deviation of predicted production and consumption and actual production and consumption the control area balance is taken which is published by the TSOs. The control area balance is defined by one of the German TSOs 50 Hertz as: '*The control area balance is the sum of all variations occurring in the respective balancing groups between the declared schedules, on the one hand, and actual customer usage and actual feed-in by power generators, on the other. The control area balance is shown as average demand value in megawatts (MW) for every 15-minute interval.*' This is the imbalance which has to be settled in order to keep the grid stable. This data is used from all TSOs in Germany while for Spain the measured net deviations are used as a measure for the imbalance volume.

CAUSES OF IMBALANCE

There are several causes of imbalance, these can be separated into two groups namely imbalance caused by generation deviation and imbalance caused by load deviation. Imbalance caused by generation is usually due to a technical error since conventional power plants can be controlled quite accurate. As most conventional power plants are quite accurately managed, most deviations from the planned generation are caused by errors.

Load deviation from expected load can have several causes. As it is not feasible to forecast the power usage for every consumer separately (both residential and commercial) there are different profiles for consumers although some large consumers are estimated separately. In these profiles there are expectations about when and how much electricity is being used. For a household, this includes a time in which they expect people to go to bed or leave the house. Since load profiles are planned on a quarterly hour basis, the forecasts are difficult. This is why all consumers in the control area are aggregated in which part of the load deviations is leveled out.

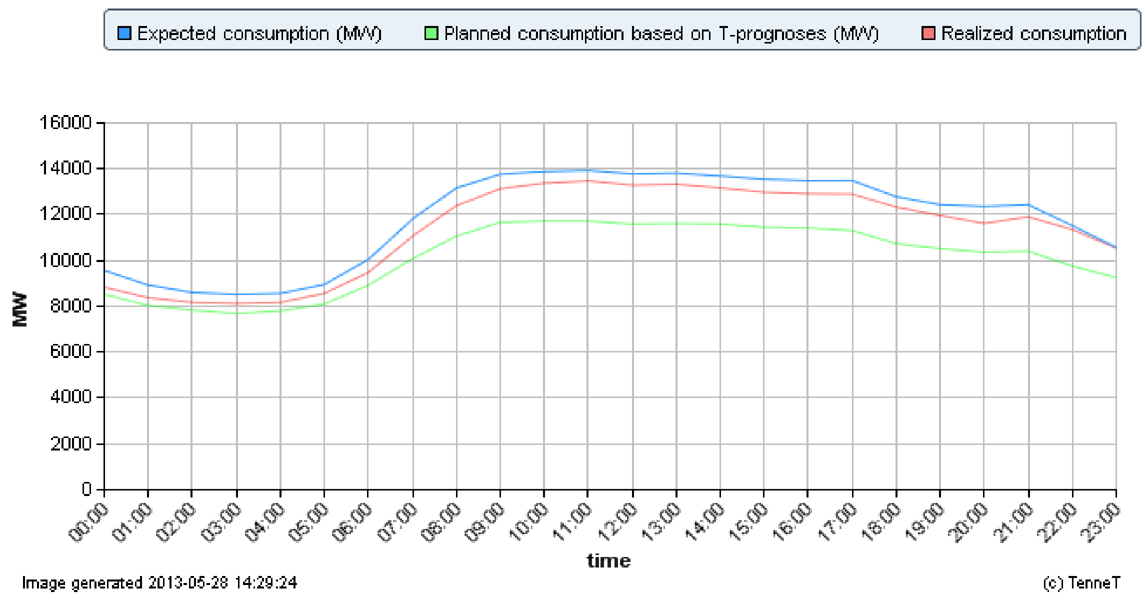


FIGURE 5: FORECASTED AND ACTUAL LOAD IN THE NETHERLANDS 28-5-2013 (TENNET)

Another issue regarding balancing load with generation is that generation is done in steps per Program Time Unit (PTU) which is the timespan in which the schedule is changed. In the Netherlands and Germany the PTU is fifteen minutes while the PTU in Spain is one hour. As can be seen in Figure 5 the load profile is a fluent profile which does not change in blocks of 15 minutes. This problem is shown in Figure 6 in which the load curve is shown as a fluent line while the schedule is in blocks per PTU. This results in a mismatch between generation and consumption which can result in imbalance. The imbalance is settled every PTU as shown in the graph while the load changes fluently. When the duration of the PTU is changed, this influences both the TSO as the BRP. When the PTU is longer the TSO has more imbalance to settle, when there is shorter PTU the BRP has more imbalance as it has to predict the load more accurate in a shorter time span.

As predictions tend to be better close to real-time, it would be expected that the imbalance is less in the beginning of the day when the deadline for the energy program was relatively short. This deadline is called the Gate Closure Time (GTC). BRPs have stated that a later GTC would result in fewer imbalances, so the imbalance is expected to be higher in the end of the day. This is however not true, the imbalance remains constant over time and is more dependent of load. This means that the BRPs have found other ways to balance their portfolio, this can be bilateral trades, own generation/load control or in some countries an intraday market (Frunt, Kling, Hermans, Nobel, & Boer, 2010).

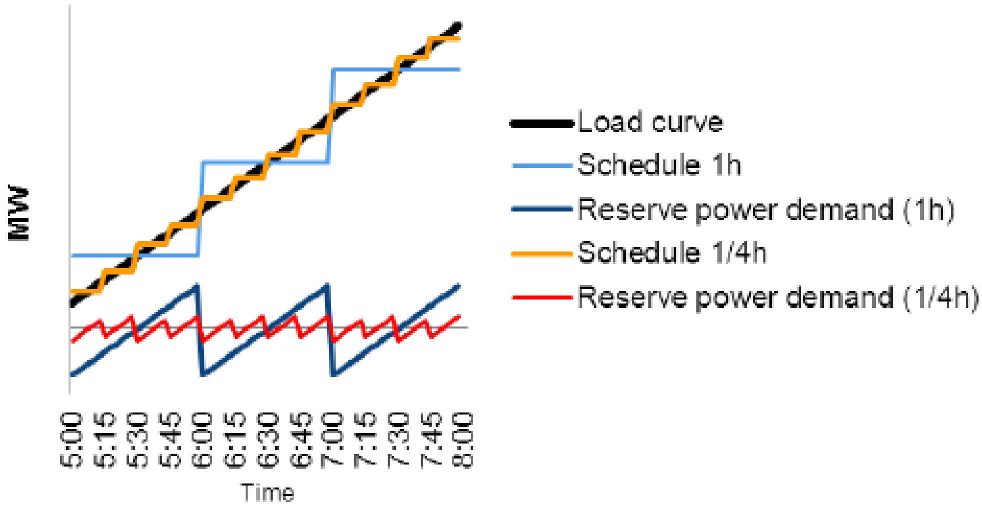


FIGURE 6: LOAD PROFILES AND SCHEDULES TOGETHER WITH RESERVE POWER DEMAND (HIRTH & ZIEGENHAGEN, 2013)

There are several cases which influence electricity usage. Since BRPs do not check households regularly it can take months before certain changes are known. These changes can have several reasons, an empty house, change of use profile of the building (a villa can be used as an office), change of number of people living/working, holiday, installation of solar panels, change of appliances, electricity price etc. Since the meter is only checked annually, changes will not be noticed instantly by the BRP. One household does not have a big impact on the balance of the control area, but changes in multiple households can affect the balance of the grid. When multiple houses install solar panels on their house and become producers instead of consumers on certain times of the day, this can result in imbalance. As it takes some time for the BRP to discover these changes, they keep working with the 'old' profiles.

To forecast consumption there are different models; daily models and hourly models. The hourly models tend to be more accurate and are simpler as there is no calculation on the weather condition for that time of the day. Only the weather for that day has to be found since the model is based on a particular hour of the day. There is some discussion about treating each hour as a different series (Ramanathan, Engle, Granger, Vahid-Araghi, & Brace, 1997) but most people use the hourly models (Cancelo, Espasa, & Grafe, 2008). Another issue is public holidays which can be treated as Sundays or can be smoothed or replaced by a similar load of the previous week (Taylor, 2003) (Smith, 2000) (Hippert, Bunn, & Souza, 2005).

There are also cases from which it is easy to estimate how much the electricity usage is. These are for instance street lights which do not have a variable consumption and switch on and off at certain times. Their usage can be calculated quite accurate and the usage is hard to meter as there are a lot of different lights which would need a lot of meters so this is usually done by calculations. All these uncertainties result in prediction errors which are partly leveled out by each other. All together keeping the grid balanced is done reactive for a large part. As generation is also a part of the estimation made for the next day, a deviation from the predicted output will also result in deviation from the energy program. For conventional power plants this is usually only a part of all imbalances as they can be controlled very accurate. A power plant failure will have a large impact on the balance of the grid and is handled by ancillary services.

ANCILLARY SERVICES

When the grid is in balance, its frequency is 50 Hz, when the demand and supply are not balanced this frequency will deviate. Frequency deviation can harm electrical devices as they are designed for 50 Hz frequencies. Large imbalances can harm the grid as well which can result in black outs. To prevent deviations, ancillary services are used which are services to balance the system. Imbalance is settled in real-time using control power which is activated to bring the frequency back to its standard level. The control power comes from power generators which will generate more or less than scheduled in order to meet the total demand.

There are three main major categories in which these services can be divided (UCTE, 2009):

1. Primary control, which is used for frequency containment and which is based on automated response within 30 seconds when frequency deviations occur;
2. Secondary control, which is used for frequency restoration to have the frequency back to its nominal value, after 5 minutes it is activated automatically; and
3. Tertiary control, which is used to restore the required level of frequency restoration reserves and which is based on manually instructed reserves which take up to 15 minutes to activate.

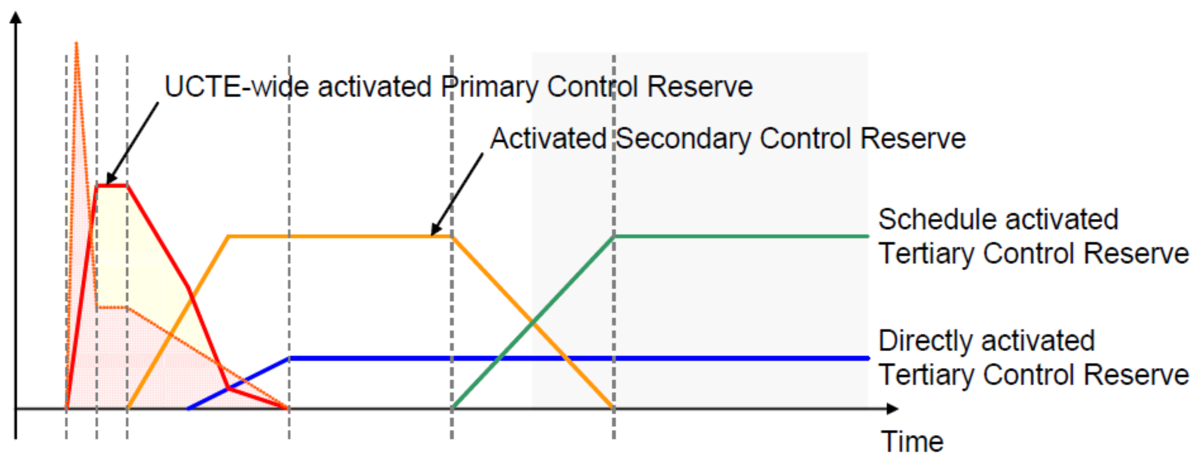


FIGURE 7: FREQUENCY DEVIATION AND ACTIVATION OF RESERVES (UCTE, 2009)

MARKET STRUCTURE

The Dutch electricity market is designed so that maintaining balance is a responsibility of every consumer. This means that each party with a connection to the grid has this responsibility. Since it would be very inefficient when every consumer has to estimate its own energy usage and follow this profile, the BRPs take the responsibility for this. To make sure BRPs will balance their portfolio as much as possible a system has been designed in order to give them an incentive to balance their portfolio. According to the Entso-e[1] balance responsibility is '*the responsibility for keeping the net balanced on all connections within its control and facing the liability consequences if this is not achieved. The (derivative) liability in case of imbalance involves the payment of an imbalance charge to the operator of the market area. The imbalance charge consists of an imbalance price for each MWh of imbalance that has occurred during a predefined settlement period*' (ETSO, 2007). Since the BRP aggregates the consumers, the uncertainty is less as some deviate up and some deviate down. Large consumers have a meter which can measure the electricity consumption per PTU.

The incentive for the BRP to balance their portfolio is done by a pricing scheme for which the BRP that causes imbalance pays a penalty. The BRP with opposite imbalance in its portfolio will receive a payment for its balancing action, which is called passive contribution. This is also why it can be interesting for a BRP to be 'long' instead of 'short' which would assume a BRP might slightly generate more power than it consumes. This can however resolve in high costs as well when the whole system is long and the BRP has to pay. In the Netherlands there is also a so called 'prikkelcomponent' which is an incentive component in the form of an additional price of imbalance in order to get a bigger incentive for the BRP to balance when too much imbalance is occurs. This incentive component will be increased when one of the next criteria is not met:

- *'the number of inadvertent exchanges over five minutes that, converted to MW, are greater than 300 MW and less than -/- 300 MW, is less than 40;*
- *the weekly average of inadvertent exchanges over five minutes, converted to MW, is greater than -/- 20 MW and less than 20 MW'* (Tennet, Incentive Component 2013, 2013).

The incentive component is found to be zero for most of the time.

PAYMENTS

There are different ways to procure balancing services for the TSO; these can be long term contracts, biddings and bilateral contracts. Every day a bidding can be done for balancing capacity for the next day; this creates the possibility for the BRP to provide this balancing service. By doing this, the BRP can use part of its flexibility providing balancing power and thus optimize profit. These are call options which give the TSO the right to activate them when needed but the TSO is not obliged to activate them. In order for the TSO to have enough capacity, contracts with BRPs are also made on beforehand and generators with more than 60 MW capacities are obliged to offer the amount which they can modify in their production or load capacity (Tennet, Uitvoeringsregels met betrekking tot, 2012). After GTC the bids are aggregated by the TSO for every PTU together with the contracted bids. Then in real-time the TSO measures the Area Control Error (ACE) which is the control area's imbalance. This is done every four seconds and in the case of imbalance, balancing capacity will be requested.

PRICING

In order to select the BRP which shall provide the balancing capacity, the ACE is processed in a Processed Area Control Error (PACE) which estimates the required balancing capacity together with the biddings. The PACE will match the bidding ladder which will be done in merit order in

[1] The entso-e is the European network of transmission system operators which provides information for and about the TSOs in Europe. Their mission is to promote important aspects of energy policy. More information can be found on: https://www.entsoe.eu

which the lowest biddings will be called first. In some countries however there is a pay-as bid mechanism which results in different prices for every amount of activated control power (Etso, 2003) (Frunt J. , 2011).

In case there is a pay-as bid structure, the selected BRP receives the price of the bidding it has made and the BRP which causes imbalance will pay the average of all biddings. This can however mean that the price for causing imbalance is not the same as the price for settling it. There is still some discussion about which is the most efficient although in general it is accepted that pay-as bid will lead to increased billing prices, while in marginal pricing the suppliers tend to bid at their overall marginal generation costs (Frunt J. , 2011).

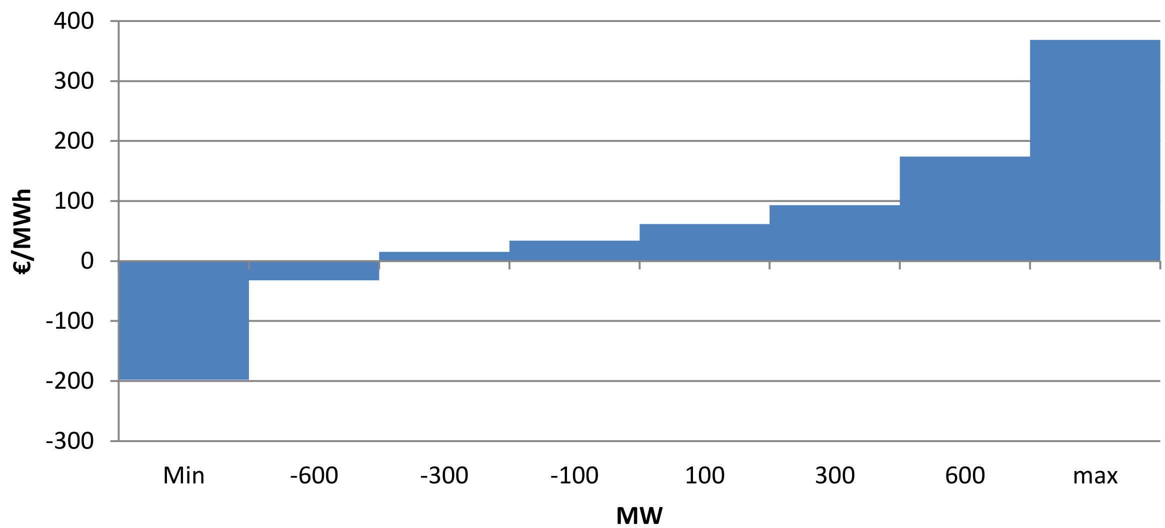


FIGURE 8: AVERAGE BID PRICE LADDER OF THE NETHERLANDS IN 2011 (TENNET)

In Figure 8 the average bid price ladder of 2011 in the Netherlands is shown. The prices are shown on the vertical axis and are in €/MWh. On the horizontal axis the amount of power made available is shown which is either positive or negative control power. This is done in steps in which the maximum or minimum power can also be made available depending on the provider. As can be seen the prices are for MWh which is dependent on the time that the power is made available. A large oversupply can also result in negative the prices.

For imbalance pricing mechanisms there are two different mechanisms; single and dual pricing. Single pricing means that one price is used for all imbalance volumes in that PTU while a different price is applied for negative and positive imbalance in dual pricing within one PTU. When single pricing is used, the actual price will be the highest price which is found in that PTU. Dual pricing is used in the Netherlands while single pricing is used in Germany and Spain (Etso, 2003).

The price for imbalance settlement has to be calculated using the price for control power and the spot price. There is a different calculation for positive and negative imbalance settlement prices, for positive imbalance the price is:

$$Price = P_{spot} - P_{imbalance} \qquad \text{(eq. 1)}$$

While for the negative imbalance price the equation is:

$$Price = P_{imbalance} - P_{spot} \qquad \text{(eq.2)}$$

From the equations it follows that the price of imbalance is dependent on the spot prices. This provides the additional costs/profit above the normal price of electricity of that moment (Frunt J. , 2011). By using this calculation the actual price of the imbalance settlement is found, other variables which influence the price like fuel prices or inflation have no impact. This calculation provides an insight in what has happened with the actual price of imbalance settlement.

The price for positive control power is higher than the spot price since additional power has to be generated. Positive control power results in varying costs like fuel and has to be generated quickly. In the case of negative control power needed, the power has already been sold by the power plant so no losses for providing less generation are made. Less power has to be generated which brings savings like lower fuel costs while the power which otherwise would have been generated will still be paid. This results in a profit without generation. Also negative prices may occur when a large surplus of power is found. This results in a payment for using electricity which can result in large profits for large consumers. It would mean that a power plant gets paid by generating less than it is supposed to do while it has already sold its electricity, resulting in double incomes. This is not a profitable situation for the electricity industry and should be prevented.

As from June 2010 Germany has implemented a uniform balancing energy price. This means that in every control area the same price applies for balancing power. These prices are based on the payments which or done in each control area for balancing energy. This is called the reBAP and is implemented by all four TSOs (50Hertz, TenneT, Amprion, & TransnetBW, Grid Control Cooperation, 2012).

9. IMPACT OF VRES AND CONTROL AREA SIZE ON THE IMBALANCE

WIND AND SOLAR GENERATION

Intermittent energy sources are sources which do not have a stable predictable/controllable generation profile. Conventional power generators can be managed quite accurately so that the output can be regulated precisely. This is not the case for wind and solar energy and they are expected to have an impact on the balancing of the grid. Wind and solar generation highly depends on the local weather conditions at that particular time. This is influenced by a number of conditions which makes it difficult to have precise forecasts. The following equation provides the amount of wind power:

$$P_T = \frac{1}{2} C_p A \rho u_o^3 \qquad \text{(eq. 3)}$$

In which C_p is the efficiency factor called the power coefficient, ρ is the air density, A the area and u is the wind speed. This equation shows that a doubling in wind speed results in a power which is eight times higher. This shows that a small difference in wind speed can result in large differences in wind power and therefore wind turbine power output (Twidell & Weir, 2005). This makes accurate predictions for wind turbine output difficult, especially on a quarterly hour basis. The forecast error reduces significantly when the time of forecasting becomes less. But since most energy programs have to be handed in a day-ahead, the forecasting period is relatively long. The forecast error has decreased a lot in recent years and continues to decrease. When the power output is aggregated the prediction error of 24 hour upfront is even less and in Germany this has gone from 6,1% in 2007 to 5,6% in 2008 (von Roon & Wagner, 2009). The forecast models are expected to become more accurate which will provide better estimations for energy programs with wind. Despite the lower forecasting errors there can still be an increase in wrongly predicted power production as the amount of wind turbines are expected to increase.

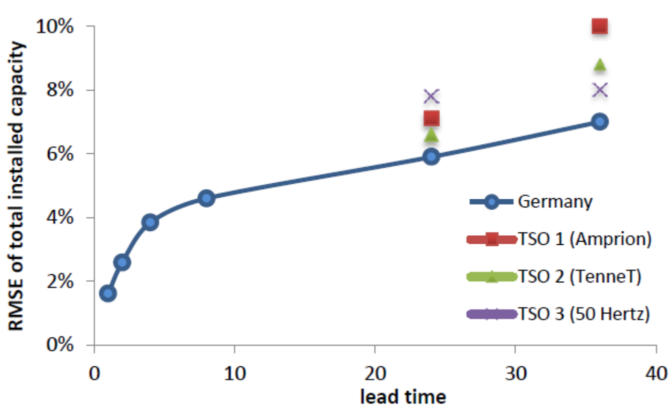


FIGURE 9: WIND FORECASTING (BORGGREFE & NEUHOFF, 2011)

In Figure 9 the wind forecast error of Germany together with three control areas are shown to give an idea about the big impact the forecasting time has on its accuracy. This graph shows that the closer the forecast is to the actual output time, the more accurate it shall be. The day-ahead forecast is relatively accurate but for grid balancing it will make a big difference. As shown in the graph the models which are used give slightly different outcomes as well depending on the lead time.

In wind forecasting a lot of research has been done in the last decades, for solar power this is a lot less. For solar power the differences in output are less as there is not a 3rd power in the equation for solar power. Research in solar power forecasting is a bit behind wind power forecasting as the amount of installed capacity solar power was negligible for grid implementation difficulties. The rapid increase of installed solar power has changed this and the effect of a lot of distributed generation has become increasingly interesting. Since more and more homeowners install solar panels on their roof this is expected to have a big impact on the grids' stability and it changes the vertical design of the grid. Other problems like congestion can be a possible side effect.

CONTROL AREA SIZE

There are multiple impacts which influence the stabilization of the grid, in Germany a lot has changed over the last decade. For instance the Grid Control Cooperation (GCC) which started in December 2008. This is the beginning of the cooperation between the German TSOs to balance their grid together. It was found that TSOs sometimes activated opposite control power to balance their grid which had to be purchased. In December 2008 the TSOs EnBW Transpotnetze AG (now TransnetBW), E.ON Netz GmbH (now Tennet) and Vattenfall Europe Transmission GmbH (now 50 Hertz) started cooperating to avoid opposite use of control power. When balancing actions are needed in the opposite direction, this imbalance can be settled by a connection between the control areas. So technically, the GCC will perform automatic netting across control area borders through an intelligent communication between load-frequency controllers of the TSOs. The imbalance is settled without purchasing control power. This results in an optimization of control power activation in Germany for all TSOs after Amprion joined in May 2010 and therefore savings of power and money. Another advantage of the GCC is the introduction of a uniform balancing energy price (reBAP) across control areas. By this, all the control areas in Germany are charged with the same balancing energy price (50Hertz, TenneT, Amprion, & TransnetBW, Grid control cooperation).

On 1 October 2011 the German TSOs have started a test operation to include the Danish grid with the GCC. On 1 January 2012 the Danish grid was permanently implemented into the GCC making it the start of the International Grid Control Cooperation (IGCC). After this, 1 February 2012 the Netherlands was included in the IGCC followed by Switzerland on 1 March 2012 and Czech Republic in June 2012. 1 October 2012 the IGCC was expanded with the Belgium TSO Elia and more partners will most likely follow. The exchange between Germany and the other countries for balancing purposes is limited with the international partners as follows (50Hertz, TenneT, Amprion, & TransnetBW, Grid Control Cooperation, 2012):

- Denmark: ± 90 MW
- The Netherlands: ± 300 MW
- Switzerland: ± 400 MW
- Czech Republic: ± 350 MW
- Belgium: ± 140 MW

These capacities are held free from scheduled in/export to keep this available for grid balancing. The interconnections in Spain are not used for balancing purposes in the grid. Spain is a net electricity exporter, interconnections capacities are used to export electricity. The connections are limited and goal is to increase the capacity with the rest of Europe which can also provide balancing capacity in the future (Sonvilla, Piria, Zane, Bracker, & Bauknecht, 2012).

10. COMPARISON OF GRID BALANCE REGULATIONS BETWEEN THE COUNTRIES

COMPARISON BETWEEN THE MARKETS

Within a country, the TSOs are responsible for a secure and reliable transport system. In the past the TSOs were only concerned about their control area which gave them the opportunity to manage the grid as they preferred. Because of current increased cooperation between TSOs, it is important to understand the differences between the imbalance management systems that are used. Differences in imbalance management can have a big impact on grid balancing which results in different imbalance properties. That is why comparisons between countries should be done with care. A good understanding of market behavior and balancing performance is important to make comparisons between countries. The TSOs provide an incentive for the BRPs to keep their area balanced by a price which changes on a PTU–to–PTU basis. This imbalance settlement design provides incentives for BRPs for certain behavior, but within these boundaries they can behave as they like. The TSOs use a variety of services to maintain and restore system frequency, as well as to restore the energy balance of the system.

Even though the German, Spanish and Dutch market regulations about control reserve are within the Union for the Co-ordination of Transmission of Electricity (UCTE) handbook[2] specifications, there are some differences. A difference can be made between technical and institutional specifications as done in (GEN, TenneT, & E-bridge, 2011). Technical specifications are differences in time or speed in which control is activated or how required reserve control power is calculated. Institutional differences are differences in regulation or organizational structures like responsibility.

TECHNICAL CHARACTERISTICS COMPARISON DE - NL

In this part, the imbalance settlement categories will be analyzed separately. The characteristics of the German and the Dutch market all fall within the UCTE, but some technical difference can be found. Some important characteristics which are observed are shown in the tables below per control power. This comparison focuses on secondary and tertiary control.

TABLE 1: SECONDARY CONTROL COMPARISON GERMANY AND THE NETHERLANDS

	The Netherlands	Germany
Activation	Automatic control signal	Automatic control signal
Min. activation speed	>7% of bid capacity/min	5 min full activation
Accessibility	Yearly tender for 300 MW load shedding capacity	Monthly capacity tenders

(TenneT, 2012) (Amprion) (Veen, Abbasy, & Hakvoor, 2009) (GEN, TenneT, & E-bridge, 2011)

[2] The UCTE operation handbook is an up-to-date collection of operation principles and rules for the transmission system operators in continental Europe. Information can be found on www.ucte.org.

The difference in activation speed for Germany provides maximum amount of time for which the secondary control is activated. However, for the Netherlands it can mean that in a lot of times the maximum time is less than 5 minutes.

TABLE 2: TERTIARY CONTROL COMPARISON GERMANY AND THE NETHERLANDS

	The Netherlands	Germany
Activation	Manual	Manual
Activation time	Within 15 min	Within 15 min
Accessibility	Yearly tender for 300 MW load shedding capacity	Daily capacity tenders

(TenneT, 2012) (Amprion) (Veen, Abbasy, & Hakvoor, 2009) (GEN, TenneT, & E-bridge, 2011)

As can be found, there are no big differences between the settlement regulations. This makes it easier to compare the two markets.

INSTITUTIONAL COMPARISON DE - NL

Below the institutional differences that were found are discussed.

TABLE 3: INSTITUTIONAL COMPARISON DE AND NL

	The Netherlands	Germany
Financial settlement time	10 days after the end of the week	Several weeks after the end of the month
Single vs. Dual pricing	Dual pricing	Single pricing
Imbalance pricing mechanism	Marginal bid price in which the highest price will be paid for all bids	$\frac{\sum \text{activated bids}}{(\text{Activated imbalance volume})}$
Regulation states	4 states	no states
Energy prices communication	Day-ahead bid ladder is published. Real-time data of imbalance and bid activation is published	Bid-ladder is known when auction results are published
Balance responsibility	All parties are balance responsible (the BRP takes the responsibility)	The TSO is balance responsible for a large share of the market including RES in feed
GTC first energy program	14:30 D-1	13:00 D-1
Deadline final energy program	45 minutes before	One hour before

(TenneT, 2012) (Amprion) (Veen, Abbasy, & Hakvoor, 2009) (GEN, TenneT, & E-bridge, 2011) (Hakvoort & Veen, 2009)

There are some differences in the institutional regulations that can have a big impact on the behavior of different parties. Real-time publishing of the balance in the Netherlands makes it possible for market parties to respond to imbalance. Therefore making it less necessary to use secondary control since the market can settle (part of) the imbalance themselves. This passive contribution is believed to result in a substantial reduction in imbalance volume.

Another difference is the pricing system for control energy, in the Netherlands a uniform price is determined by collecting all bids for a specified control action for which the highest price is the price for all activated energy. The German pay-as-bid model results in a separate price for control power for each supplier coming from their individual bid (GEN, TenneT, & E-bridge, 2011). The dual pricing scheme which is applied in the Netherlands results in a separate price for positive and negative control power if both directions of imbalance are found within one PTU. In the case of Germany the same price applies for both up and down regulation. Dual pricing is thought to give more incentives to the BRPs to balance their portfolio, but this is limited by the low occurrence of the dual state.

The Netherlands defines four different states, namely; state 1 (up-regulation), state -1 (down-regulation), state 0 (no regulation) and state 2 (two-sided regulation). Each PTU will be labeled with a regulation state, depending on this state, the price of up and downward regulation will be defined. For state 1 both up- and downward regulation are the same as the price for upward regulation. For -1 this is the case for the price of downward regulation while for state 0 the price is the average for the first bid in both directions. Only for state 2 the positive price is the marginal price for downward regulation and the negative prices for upward regulation. Since dual pricing only occurs about 10% of the time, it does not have a large impact (Veen, Abbasy, & Hakvoor, 2009).

In The Netherlands also incentive component is used above the imbalance price. This can be activated when the number and average of the involuntary exchange with the UCTE are too large. When not enough regulating power is available and emergency power is used, the price for imbalance can be enlarged by 10%.

TECHNICAL CHARACTERISTICS COMPARISON ESP – NL

The imbalance settlement categories are analyzed separately again. Same as for Germany and the Netherlands, the Spanish characteristics of imbalance control fall within the UCTE handbook. The differences between Spain and the Netherlands are given below.

TABLE 4: SECONDARY CONTROL POWER COMPARISON SPAIN AND THE NETHERLANDS

	The Netherlands	Spain
Activation	Automatic control signal	Automatic control signal
Activation speed	>7% of bid capacity/min	Fully operational within 15 min
Accessibility	Yearly tender for 300 MW load shedding capacity	Hourly tender capacities
Price	Marginal price	Marginal price

(ETSO, 2007) (UCTE, 2009)

There are no large differences between the Netherlands and Spain. The activation speed is different but this results in a similar time.

TABLE 5: TERTIARY CONTROL POWER COMPARISON SPAIN AND THE NETHERLANDS

	The Netherlands	Spain
Activation	Manual	Manual
Activation time	Within 15 min	Within 15 min
Accessibility	Yearly tender for 300 MW load shedding capacity	Every day on an hourly basis
Price	Marginal price	Marginal price

(ETSO, 2007) (UCTE, 2009)

In Spain not only control power is used but also imbalance management. This is activated after an hour and is an additional service to tertiary control power. It is a market based principle which is paid the marginal price. Imbalance management does not differ much from tertiary control power but it settles imbalance greater than 300 MWh. When activated control power is compared, imbalance management should also be added as it would otherwise result in much lower balancing energy activated than it actually is (Miguelez, Cortes, Rodrıguez, & Camino, 2008).

INSTITUTIONAL CHARACTERISTICS ESP-NL

The institutional characteristics which differ from the Netherlands are found. In Spain a single price is used and the TSO is balance responsible. Same as for Germany there are no different states used and there is no real-time information about price or imbalance. This means that there is no possibility for BRPs to 'passively' balance the grid when they see this is possible.

TABLE 6: INSTITUTIONAL CHARACTERSTICS SPAIN AND THE NETHERLANDS

	The Netherlands	Spain
Single vs. Dual pricing	Dual pricing	Single
Imbalance pricing mechanism	Marginal bid price in which the highest price will be paid for all bids	Marginal bid price in which the highest price will be paid for all bids
Regulation states	4 states	No states
Energy prices communication	Day-ahead bid ladder is published. Real-time data of imbalance and bid activation is published	Day-ahead bid curve is published
Balance responsibility	All parties are balance responsible (the BRP takes the responsibility)	The TSO is balance responsible
Transparency	Real-time information about the imbalance	After two days data is published
Deadline energy program	13:00 D-1	10:00 D-1
Deadline final program	Depending on the intraday trading session	One hour before

(Veen, Abbasy, & Hakvoor, 2009) (REE) (Sonvilla, Piria, Zane, Bracker, & Bauknecht, 2012)

In the Spanish day-ahead market, bids can be placed between midnight and 11:00 for the 24 hours of the following day. Afterwards, at 16:00 the day before the first of a total of six different intraday market sessions opens. The first is open for 3,5 hours which covers the whole 24 hour of the next day, the other five sessions are open for 2,5 hours. They have starting hours at 21:00, 01:00, 04:00, 08:00 and 12:00 (Ciarreta & Espinosa, 2010) (Miguélez, Cortés, Rodríguez, & Camino, 2007). It must be noted that from the six intraday sessions in Spain, only the first one is of siginificance in amount of energy traded. The other intraday sessions are mostly used to solve operative issues (Miguelez, Cortes, Rodrıguez, & Camino, 2008).

CONCLUSIONS

All of the balancing systems fall within the UCTE handbook but still some changes between the Dutch Spanish and German market are found. These differences can have a large impact on the imbalance settlement. For the Dutch market, publishing real-time imbalance prices provides the possibility for the market parties to react immediately. This way, not only the TSO will respond, but also market parties if they have an incentive to do so. This can be done by large users, or parties with a CHP plant. When the price is high, they can generate electricity and sell it to the grid. This means that a big increase in imbalance volume can have a smaller impact in the Netherlands than in Germany or Spain. If more CHPs would be installed, it can be the case that the imbalance will be settled by the market itself for a large share, so the TSO would have to use less control power.

Another difference is the single versus dual pricing, where dual pricing gives the BRPs a stricter incentive to balance their area. In Germany and Spain the BRPs will slightly over contract because it is less risky to have overcapacity than under capacity. This results in a decreased incentive to balance their portfolio and rather generate too much than too little power. Since the dual pricing only occurs in 10% in the time, this difference between the markets is limited. It can have a bigger impact in the future if dual pricing would occur more frequent although in the past years Tennet has tried to decrease the amount of times that state 2 occurred which makes it unlikely.

An increased imbalance in Germany does not have to mean that there will be a large amount of imbalance in the Netherlands in the future as well. Since the BRPs have a bigger incentive to accurately balance their portfolio it is likely that the imbalance will be lower in the Netherlands. If the imbalance is high, there is also a possibility in the Netherlands to settle the imbalance by market parties without interfering of the TSO. The real-time data provides the possibility for market parties to anticipate on the imbalance. An increase in Germany because of more wind and solar power will most likely still result in an increase in imbalance in the Netherlands. How big this increase is and how the market will respond might be slightly different.

For Spain it is easier to make a comparison between the markets. An increase in Spain will give a more similar increase in the Netherlands as there are less big differences between these two markets. The Netherlands and Spain both have an intraday market although they have different regulations. In Spain there are six intraday sessions which give the opportunity to trade on selected hours. In the Netherlands there is a continuously intraday market which provides the possibility to trade up to 5 minutes before delivery. It is said that the intraday market in the Netherlands is not used much, although there is no data available as a lot is done Over The Counter (OTC). The prices are based on the bid ladder for both countries which results in the marginal price. This is believed to result in the lowest price since the same price is paid for all activated energy.

11. ANALYSIS OF IMBALANCE DATA OF THE THREE COUNTRIES

SPAIN

IMBALANCE VOLUME

The absolute imbalance volume in Spain is shown in Figure 10 which is the colume of both positive and negative imbalance. An increase in imbalance volume is found since the imbalance after 2010 is higher than in 2007. Also the differences between the monthly averages are bigger after 2009 than in 2007. Unfortunately the standard deviation cannot be calculated as no data has been analyzed per PTU from 2007 - 2012. The increase in variation throughout the year is interesting as it seems that there is a yearly wave pattern. During the winter there is more imbalance than during summer, this can be the result of more wind in the summer although no direct correlation between wind output and imbalance has been found. The increase in imbalance volume seems to decline which also correlates with the decline of extra installed capacity. Caution should be taken by comparing this graph with the ones from the German TSOs as the total imbalance in Germany is the imbalance of the four TSOs added.

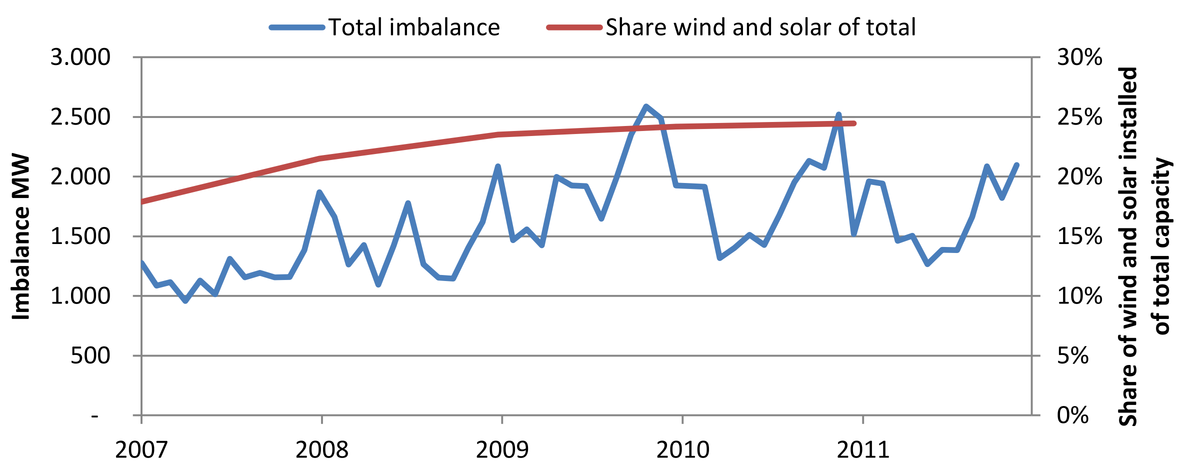


FIGURE 10: MONTHLY AVERAGE ENERGY REQUIREMENTS FOR IMBALANCES (SOURCE: REE´S ANNUAL REPORTS) (ESPANA)

CONTROL POWER USED

In Figure 11 the secondary, tertiary and imbalance control power is shown which shows a similar increase as the imbalance volume found. As discussed before, the imbalance management is also an ancillary service together with the control power. In 2007 about 1.000 MW was required for imbalance while in 2011 this was about 1.700 MW average. When the increase of the share of wind and solar installed started to decline, the increase in imbalance declined as well. This can be seen as the average imbalance in 2009, 2010 and 2011 has not changed much similar as in Figure 10. The activated balancing power is lower than the imbalance volume which means that imbalance settlement is not only done with control power. This can for instance be done by BRPs which balance their own area by adjusting the generation themselves in real-time in order not to cause any imbalance.

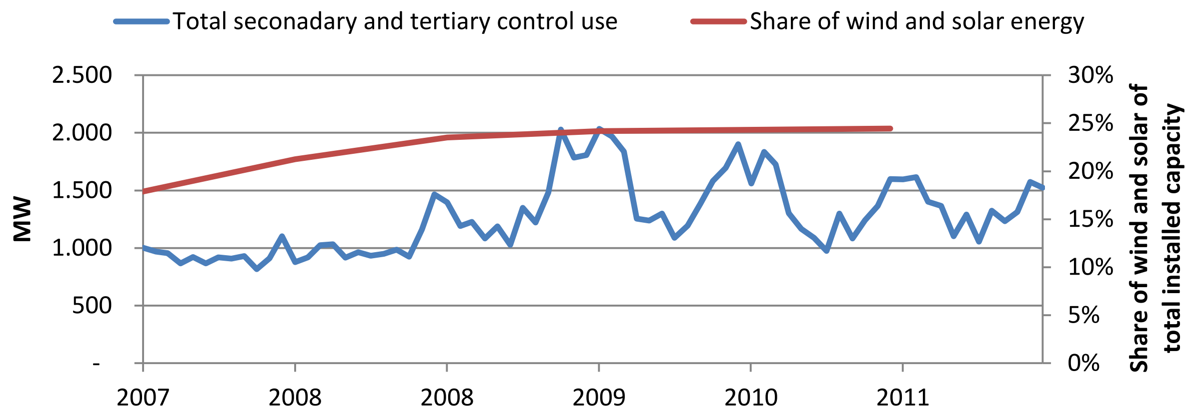


FIGURE 11: MONTHLY AVERAGE IMBALANCE MANAGEMENT, SECONDARY AND TERTIARY CONTROL POWER USED (REE)

The imbalance management which is used in Spain as well has large share of the activated control power as can be seen in Figure 12 which shows the control power used separately. This graph shows that at the times of large peaks in imbalance, this results in a large increase of imbalance management and on a lower level an increase of tertiary control power. So for large deviations more imbalance management is used. Since imbalance management is only activated after an hour, it is likely that it is used for events which last longer.

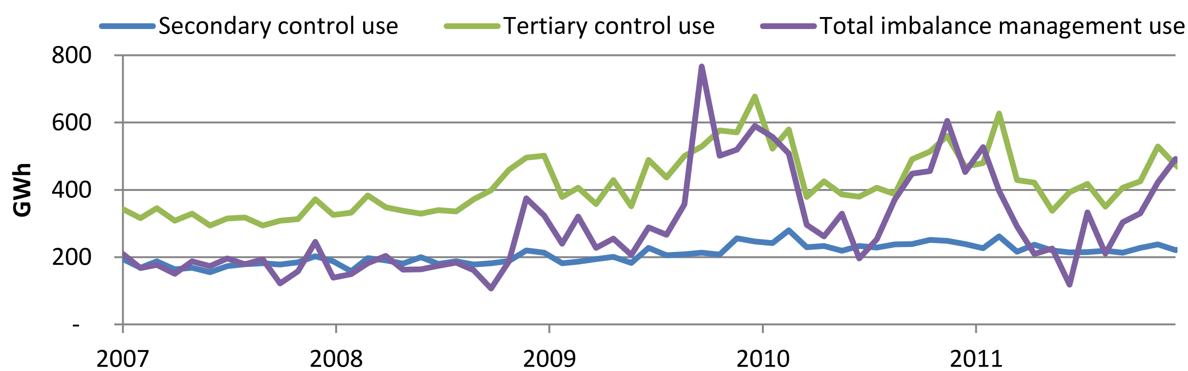


FIGURE 12: MONTHLY AVERAGE CONTROL POWERS USED TO SETTLE IMBALANCE IN SPAIN (REE)

GERMANY

TENNET DE

Tennet DE has the biggest control area of the four TSOs which reaches from the North to the South of Germany. This makes that it has good conditions for both wind and solar energy in Germany. In the North, both on- and offshore wind energy is installed while in the South the conditions for solar energy are good.

IMBALANCE VOLUME

The volume of the imbalance has been studied; first the absolute volume has been analyzed. In Figure 13 it is found that the absolute volume has increased rapidly since 2001. In the years 2001 – 2005 the imbalance seems to stay relatively stable. After 2005 however, the imbalance rises quickly resulting in a doubling in the total ten years. When looked at the share installed capacity for wind and solar energy in the Tennet DE control area, it can be seen that the share rises quite rapid from 2002. In less than ten years the share has gone from 10% up to more than 40% in the Tennet DE control area. From this graph, there seems to be a correlation between the amounts of solar and wind installed capacity and imbalance volume. Early 2010 a lot of imbalance is found, this is the result of a period of high imbalance volumes rather than one or two large peaks. The reason for this high imbalance is not known. It did not occur in the control areas of the other TSOs in Germany so it has to do with something within the Tennet DE control area. In between July 2009 and April 2010 the data was found unreliable. There were too many cases of zero imbalance which should happen only in 0,1% of the time. This is why this data has been left out of the graph. The increased amount of wind and solar installed capacity has increased by 442% from 2.727 – 21.458 MW which results in a share of 41% while the imbalance has doubled (50Hertz, Amprion, APG, TenneT, & TransnetBW).

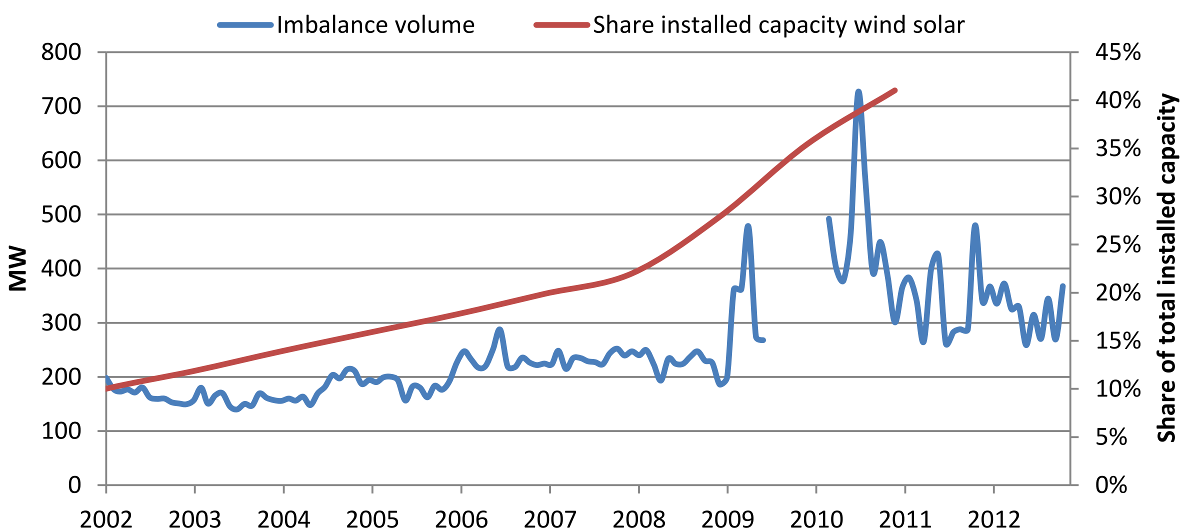


FIGURE 13: MONTHLY AVAERAGE IMBALANCE VOLUME PER PTU TENNET (TENNET) (50HERTZ, AMPRION, APG, TENNET, & TRANSNETBW)

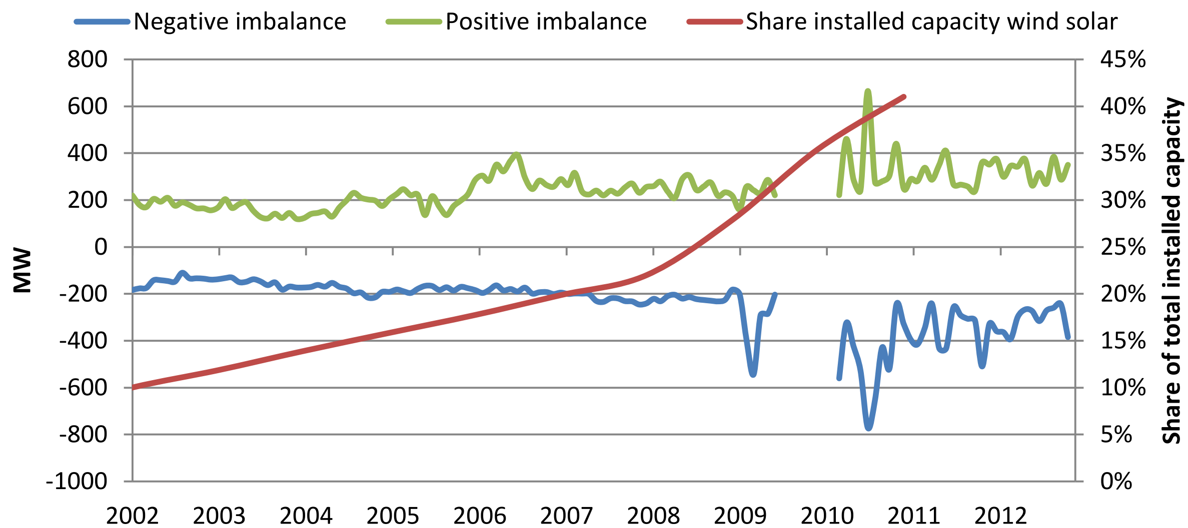


FIGURE 14: MONTLHY AVERAGE OF POSITIVE AND NEGATIVE IMBALANCE VOLUME TENNET

Figure 14 shows that both the positive and negative imbalance increase, although the positive imbalance seems to be a bit higher there is no clear domination of imbalance in one direction. For this control area there was no clear difference between negative and positive imbalance. They are both similar; there is not a dominant side in which imbalance is found.

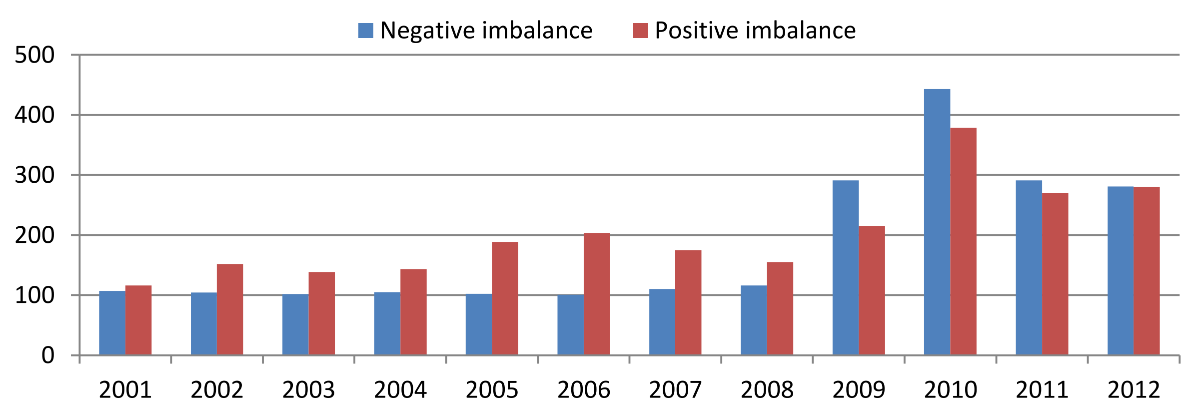


FIGURE 15: STANDARD DEVIATION IMBALANCE VOLUME

In Figure 15 the standard deviation is given which shows that the standard deviation has become larger. This implies that the data is more spread; the data has more values far from the average. This implies that the grid is less stable and needs more stabilization actions. The standard deviation starts to increase rapidly after 2008 which is also the period in which a lot of solar generation is installed and the share of installed capacity has become larger than 20%.

IMBALANCE VOLUME

50 Hertz has its control area in the east part of Germany. In the graph below the same correlation can be found although no data from before 2006 is available. It is clear that the absolute volume has increased since 2006 and seems to continue to keep increasing as the share of VRES keeps increasing.

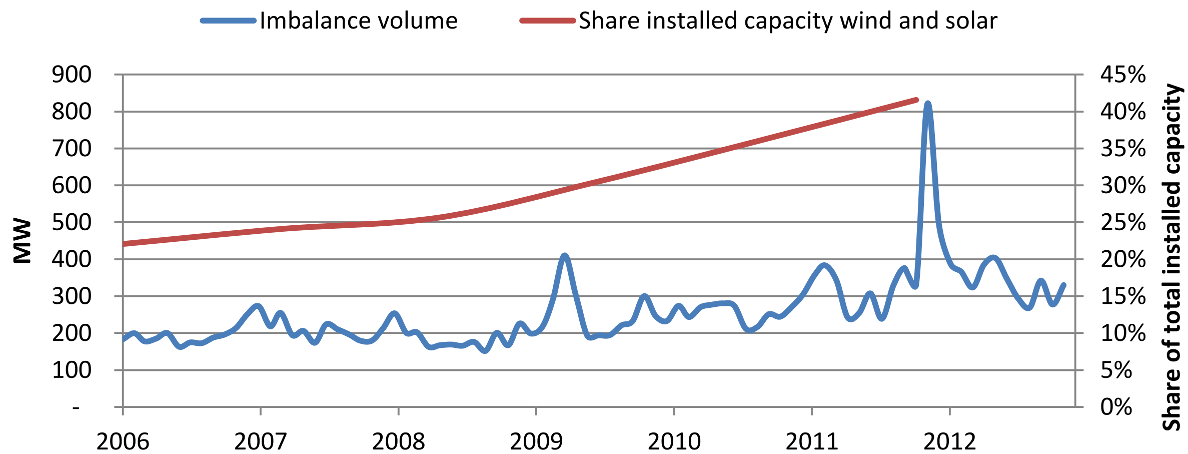


FIGURE 16: MONTHLY AVERAGE IMBALANCE PER PTU 50 HERTZ (50HERTZ) (50HERTZ, TENNET, AMPRION, & TRANSNETBW, 2012)

The rise of imbalance is considerable in Figure 16, from 2006 – 2011 the average imbalance per PTU has gone up by 86%. This rapid increase in only 5 years correlates with the 88% rise of installed wind and solar capacity from 8.513 – 16.012 MW in the same period. The peak in December 2011 and January 2012 is mostly caused by restructuration of the marketing process for wind power. Since 1 January 2012 it is possible for wind park owners to choose a fixed RES-tariff or to sell their power directly on the market. In this transition period 50 Hertz noticed high forecast errors in wind energy which can be seen in the imbalance. This shows that wrongly forecasting of wind power has a big impact on the imbalance in the grid.

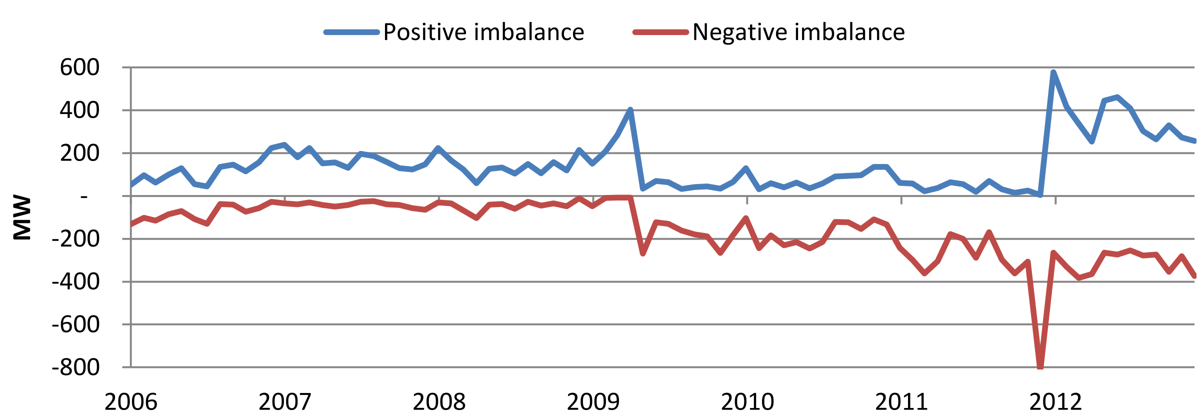


FIGURE 17: MONTHLY AVERAGEVOLUME OF NEGATIVE AND POSITIVE IMBALANCE PER PTU 50 HERTZ

Figure 17 shows that for both the positive and the negative imbalance, the volume keeps increasing. Before 2009 the positive imbalance volume is relatively high compared to the negative volume, after 2009, the share of negative imbalance volume of the total imbalance is higher. As this is the only control area in which this is found, it is not clear what the reason is.

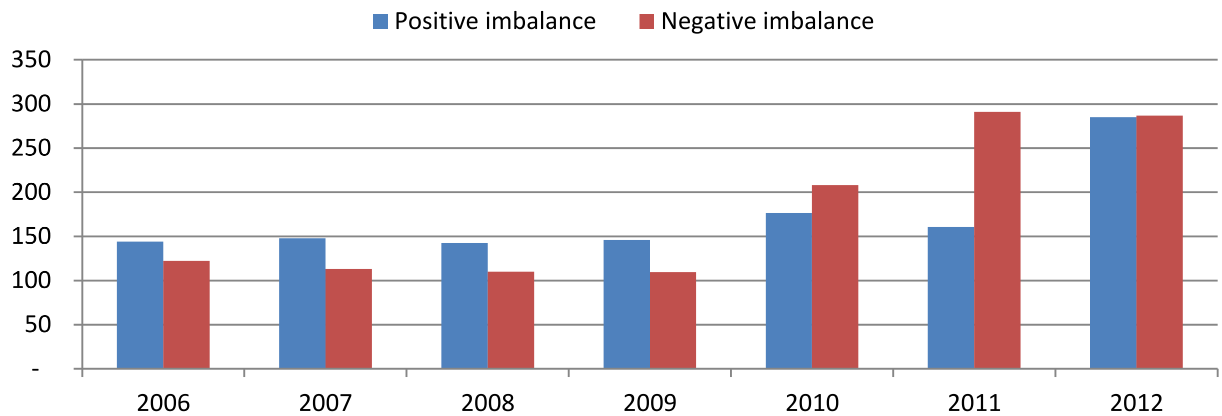


FIGURE 18: STANDARD DEVIATION POSITIVE AND NEGATIVE IMBALANCE 50 HERTZ

The standard deviation is given in Figure 18 and again the standard deviation increases. This implies more data points that are far from the average or more extreme imbalance. After 2009 an increase is found which is the same period in which more solar generation has been installed.

SECONDARY CONTROL POWER USE

As the imbalance volume has increased over the last years, it is expected that this results in the use of more secondary control power. Since the grid has to be stabilized, it is expected that the TSOs will actively use more balancing actions. This is the case when no changes are made in the balancing mechanism, but some changes in the grid like the IGCC can also have an impact. The IGCC provides the possibility for control areas of different countries to settle their imbalance automatically when they are in opposite imbalance directions. It will help settle the imbalance automatically and as a result less control power is needed. In 2008 the German GCC was implemented in which the German TSOs started cooperating to balance the system.

TENNET DE

In the Tennet DE control area it was found that the measured imbalance volume has increased. This would result in an increase of actively balancing actions by Tennet DE by using more secondary control power. In Figure 19 the secondary control used by Tennet DE shows that it has decreased substantially. This is also found by Hirth and Ziegenhagen which claim that there is a week correlation between the amount of reserved capacity and the installed capacity wind and solar (Hirth & Ziegenhagen, 2013). This is the case as although the imbalance volume did increase, but less control power was used to balance the grid.

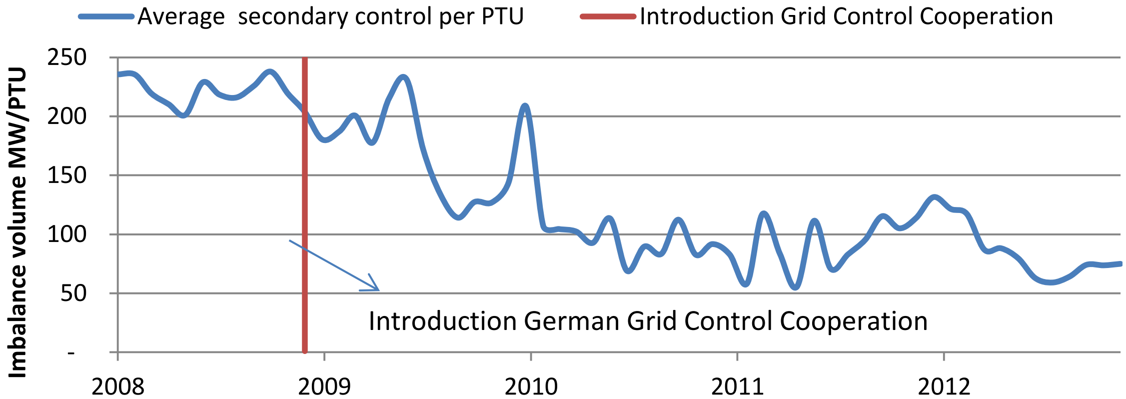


FIGURE 19: MONTHLY AVERAGE ACTIVATED SECONDARY CONTROL PER PTU TENNET DE

In the graph it is shown that the German TSOs started to cooperate on 1 December 2008. Since only data is available from after January 2008, it is difficult to show the amount of secondary control power use with an increase in solar and wind energy from before 2008. In Figure 19 however, it clearly shows that after December 2008, the secondary control power used has decreased while the amount imbalance has increased as was shown in Figure 13. In Figure 20 the imbalance volume and secondary control use are shown in one graph. It is clearly noticeable that before the GCC started, the two are almost equal. After the GCC started working, the imbalance volume keeps increasing but the secondary control use decreases. An increase of imbalance of about 80% while a decrease of about 40% of secondary control power used was found.

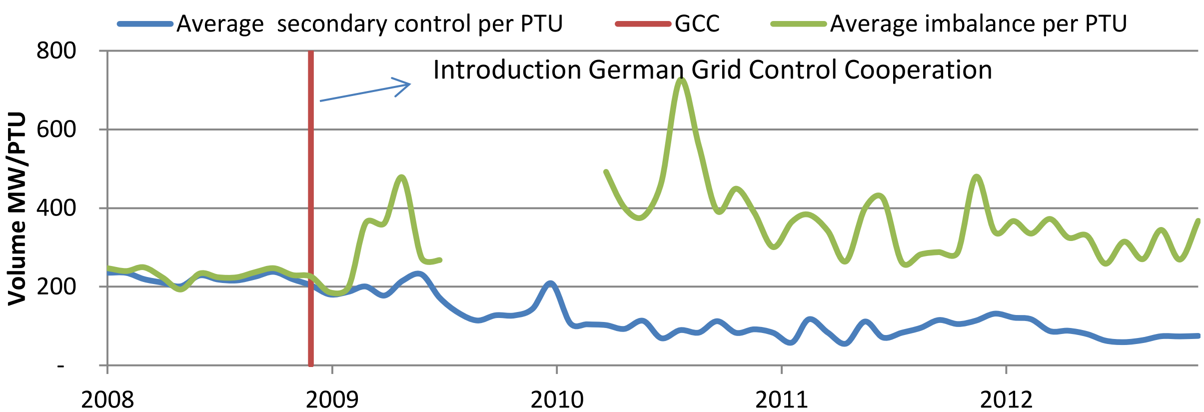


FIGURE 20: MONTHLY AVERAG IMBALANCE AND ACTIVATED SECONDARY CONTROL PER PTU TENNET DE (TENNET)

50 HERTZ

For 50 Hertz it is, same as for Tennet DE, found that the imbalance volume has increased. To settle this increased amount of imbalance it is expected that more secondary control power is used. Figure 21 shows, similar as for Tennet DE, a decrease of secondary control used.

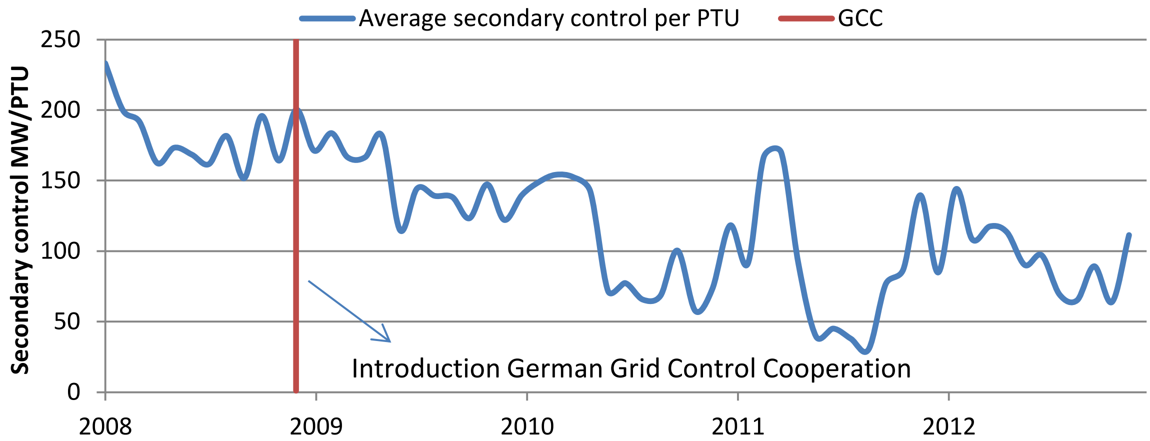


FIGURE 21: AVERAGE MONTHLY SECONDARY CONTROL USED PER PTU 50 HERTZ

In this graph there is also a clear decrease in secondary control power activation after December 2008, although it is not clear whether this decrease started before 2008. In Figure 22 the imbalance volume and secondary control use are shown in one graph and again it is found that before the GCC started operating, the imbalance volume and secondary control power used were almost equal. Again after the GCC the imbalance volume kept increasing while the secondary control power activated has decreased. An increase of the imbalance volume of about 45% and a decrease of the secondary control power used of about 50% can be found. This graph shows a big similarity with Figure 20 which shows the large impact of the GCC.

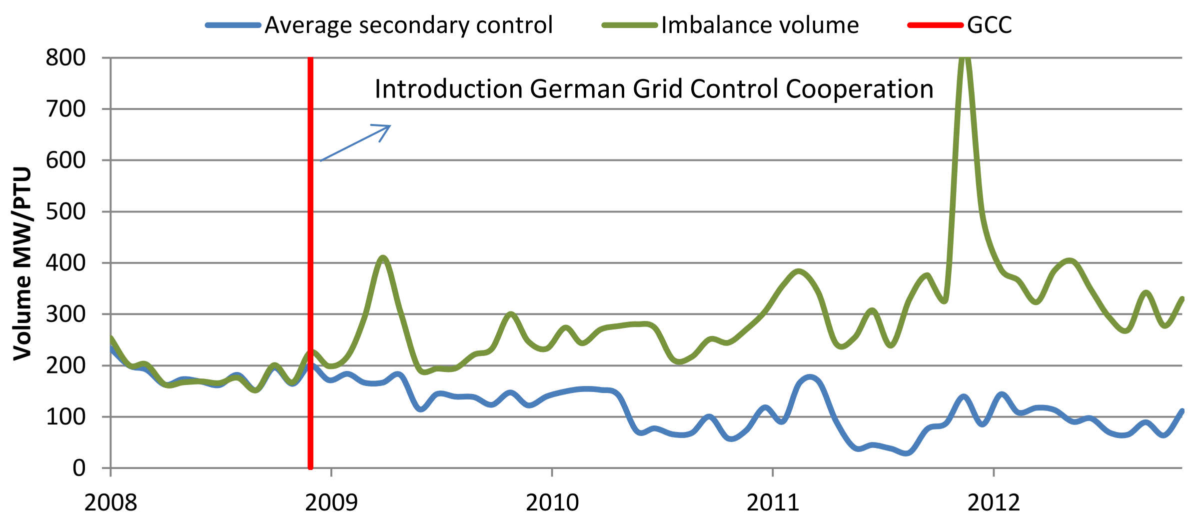


FIGURE 22: IMBALANCE VOLUME AND SECONDARY CONTROL USED

This data show that despite an increase of imbalance volume which is most likely due to intermittent generation, the activated control power has decreased. The activated control power is about $\frac{1}{3}^{\text{rd}}$ of the imbalance volume which has resulted in a big saving of control power.

IMBALANCE VOLUME IN THE NETHERLANDS

The imbalance trend as can be seen in Figure 23 shows a decrease until 2005 after which a small increase is found. The decrease of imbalance cannot be appointed to load decrease as the load has only increased in the last decade. In this graph it shows that the imbalance has gone down from 2002 – 2005 after which it slowly increased. The decrease until 2005 was a learning rate of the market. After this decline a slow increase from 2007 is found which is possibly due to passive contribution as the prices are published together with the other balance data (Nobel, 2013). This is a substantial increase of about 17%; the increase of consumption in the same period is about 3%. It is found that the share of solar and wind energy decreased in the years 2008 – 2010. This is not due to less installed capacity, more solar and wind energy had been installed, but more conventional power plants have been installed during this time as well.

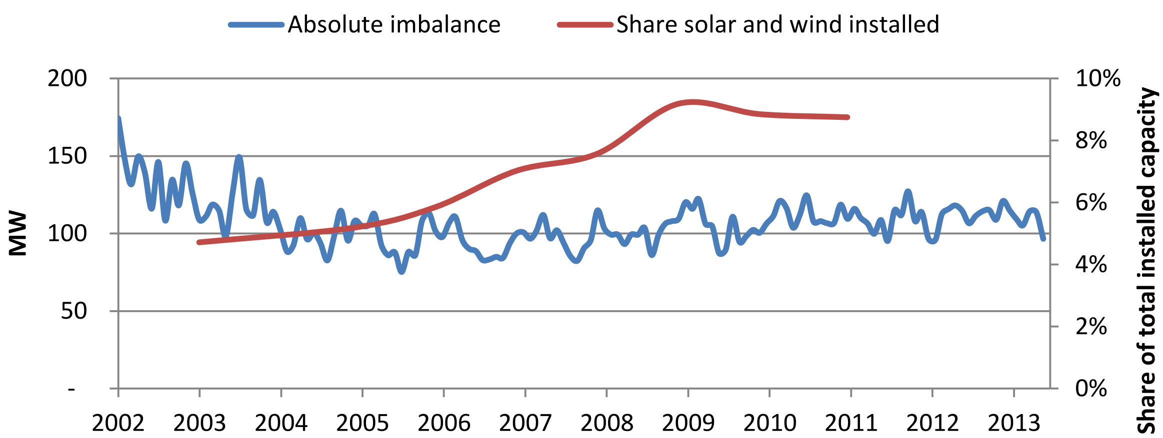


FIGURE 23: MONTHLY AVERAGE IMBALANCE PER PTU IN THE NETHERLANDS

The imbalance in the Netherlands does increase, even though the consumption increases a lot less and the amount of installed wind and solar capacity has even decreased the last years. In this graph a yearly wave profile can be found as well; this is most likely due to the fact that people change from BRP in the New Year which results in adjustment difficulties in the energy programs of the old and new BRP. The BRPs learn throughout the year which results in a decrease of imbalance after which it starts again in the next year (Nobel, 2013). This is a clear effect of the complete liberalization of the electricity market in the Netherlands in which it is easy for individuals to change between energy providers. The share of the amount of wind and solar capacity has decreased in the last years. This is not because less MW has been installed, but because more conventional power plants have been installed leading to a lower share of the amount of wind and solar generation capacity.

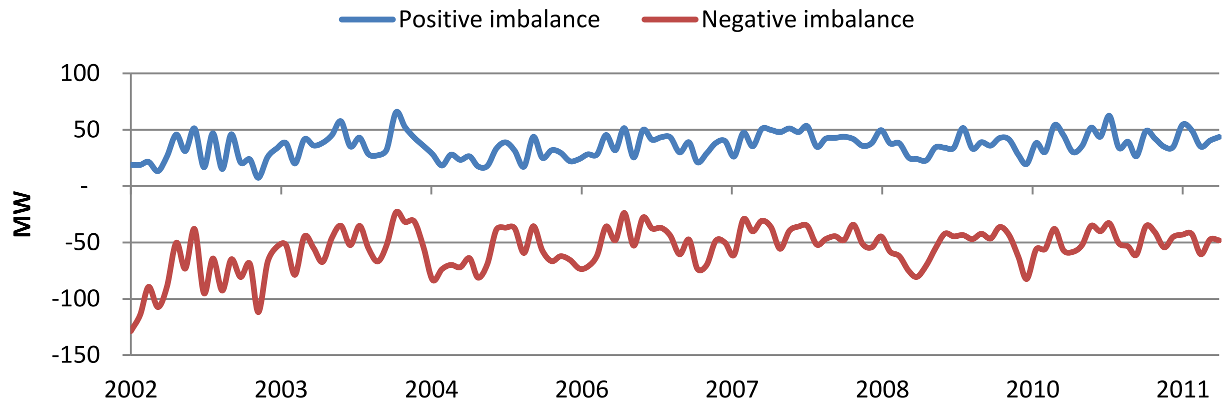


FIGURE 24: MONTHLY AVERAGE VOLUME OF IMBALANCE VOLUME PER PTU IN THE NETHERLANDS

From Figure 24 is found that there is not a dominant direction of imbalance volume. Both positive and negative imbalance are around 50 MW.

CONTROL POWER USAGE IN THE NETHERLANDS

The control power usage in the Netherlands is almost equal to the imbalance volume found in Figure 23. The amount of activated control power is a bit lower than the imbalance volume but has a similar shape.

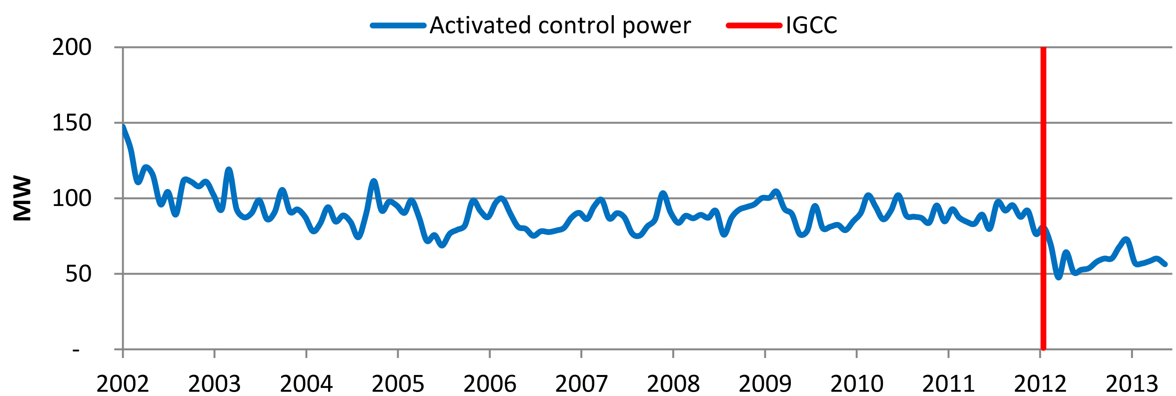


FIGURE 25: MONTHLY AVERAGE ACTIVATED CONTROL POWER PER PTU INT THE NETHERLANDS (TENNET)

What can be noticed is that the amount of activated control power in the Netherlands has decreased a lot since the Netherlands has joined the IGCC. In Figure 25 it is found that same as for Tennet DE and 50 Hertz, the imbalance volume and the activated control power are almost equal until the participation to the IGCC.

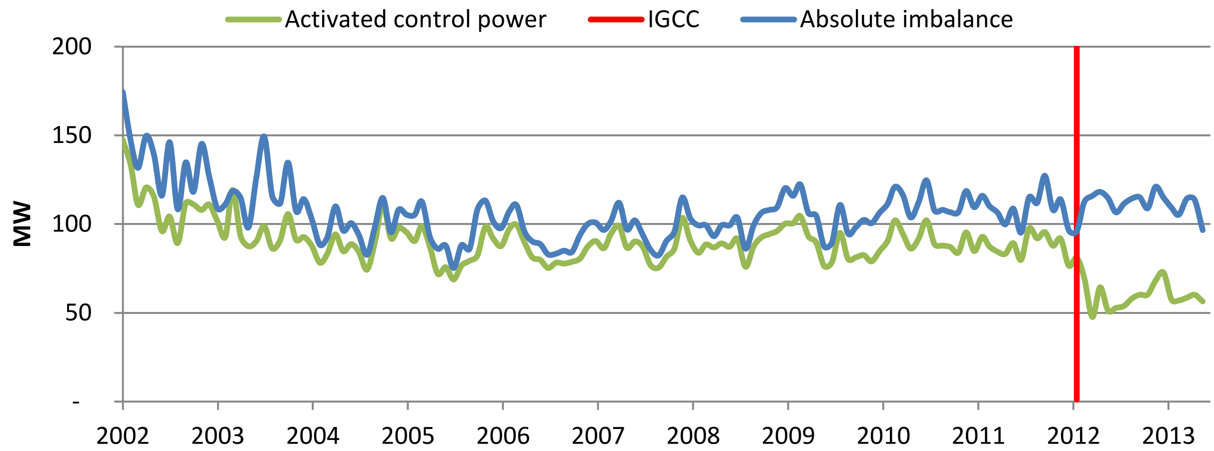


FIGURE 26: MONTHLY AVERAGE OF IMBALANCE VOLUME AND ACTIVATED CONTROL POWER PER PTU IN THE NETHERLANDS (TENNET)

Figure 26 shows the same decrease of activated control power after participation to the IGCC as for the German TSOs. The amount of activated control power is only 55% of the total imbalance volume after the cooperation of the TSOs. It is very likely that the control power usage in the Netherlands will decrease even more when more countries will participate in the IGCC with interconnections with the Netherlands.

CONCLUSION OF THE IMPACT OF INTERMITTENT GENERATION ON THE IMBALANCE

Comparing the countries with each other to find the impact of intermittent generation on the imbalance market, the data of the different TSOs has been analyzed. Data of Spain, Germany and the Netherlands has been put into one graph in which the share of wind and solar of the total installed capacity is put on one axis. The share of imbalance of the total consumption can be put on the other in order to provide some insight in the impact of wind and solar on the imbalance. Data of consumption has been used as it is usually based on more precise measurements. A lot of times consumption is referred to as load, which is not the same. Besides that, the vertical grid load is published on the websites of the TSOs which is different from the actual load and should therefore not be used as load. Vertical grid load only includes the power transferred from the transmission network to the distribution networks and end consumer (TenneT, Vertical grid load). Since this does not include distributed generation, which includes solar and most of the wind generation, a lot of the power is missing. The definitions for load and consumption according to the Entso-e are: '*Load is the power consumed by the network including (+) the network losses but excluding (-) the consumption for pumped storage and excluding (-) the consumption of generating auxiliaries*'. While consumption is defined as: '*It is the net electricity consumption including network losses without consumption for pumped storage*' (Entso-e, 2013). For this figure, data of the consumption is found for 50 Hertz (50Hertz, Almanac 2011, 2011), while the consumption data for Tennet DE and Amprion has been calculated from the total German consumption in which the share is found based on historical figures. The consumption of Germany can be found at the Entso-e website.

Figure 27 shows that there is correlation between the share of installed VRES capacity and the share of imbalance. More research should be done on this matter since more data should be analyzed of preferably different countries. What can be assumed is that under a certain share of VRES of the total installed capacity, the impact is low. After about 20% of installed VRES it shows that the share of imbalance starts to increase. From this it can be concluded that the impact of VRES on the imbalance is substantial after more than 20% of total installed capacity has been installed.

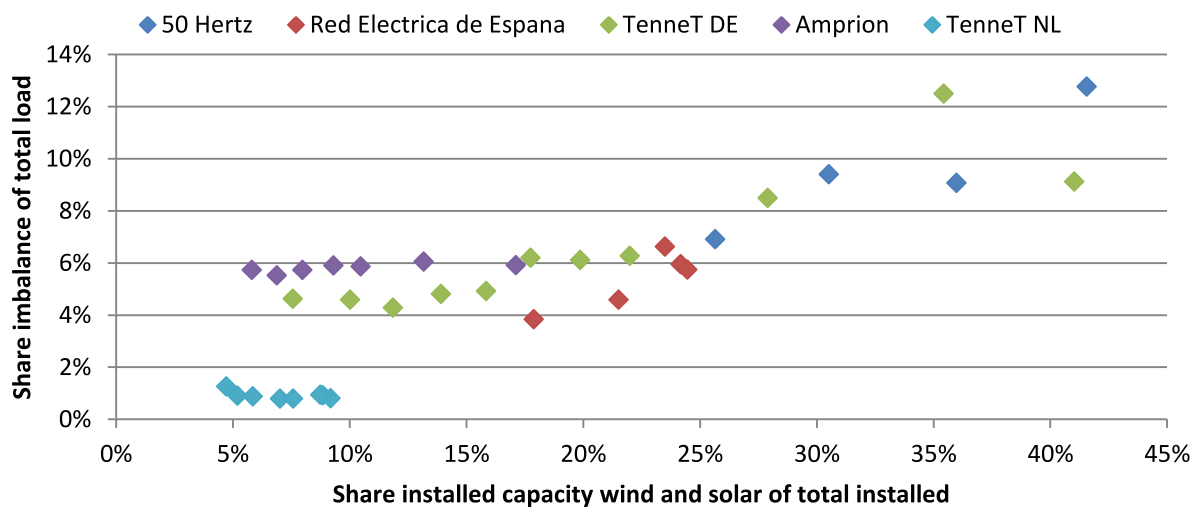


FIGURE 27: SHARE OF IMBALANCE OF CONSUMPTION VS. SHARE OF WIND AND SOLAR INSTALLED OF TOTAL INSTALLED CAPACITY

The low share of imbalance in the Netherlands is interesting and this graph shows that is much lower than the other countries even at times when the share of wind and solar generation was the same. This lower imbalance is thought to be the result of the real-time publishing of imbalance data. This way certain parties can increase or decrease their generation and therefore balance the grid. This form of passively balancing is only possible in the Netherlands as there are no other countries in Europe which publish real-time data of the imbalance.

For Figure 27, data of the German TSO Amprion is also used. Since not all data for analysis was available from Amprion it is chosen to focus on the German TSOs Tennet DE and 50 Hertz. The data of control power and imbalance volume can however be found in appendix A.

CONSLUSION OF THE IMPACT OF THE INCREASE OF THE CONTROL AREA ON THE IMBALANCE

The implementation of the German Grid Control Cooperation can be seen as an increase of the control areas. 50 Hertz only has a connection with Tennet, so its control area only increased by a limited amount. A bigger control area is likely to result in a lower imbalance as the imbalance of different BRPs level each other out as done with the IGCC. An even bigger control area with more interconnections would result in more saving and is definitely an interesting option for Europe. The impact of an increase of the control area has been studied but to find the actual increase together with the savings in control power activation more research should be done. To find the decrease in control power activation by the size of the control area, the control power usage of all the countries that cooperate should be studied. The entire market of the cooperating countries from before and after should be added to see the decrease. Unfortunately for Denmark the amount of used control power is not available and even from Germany not all data is available from before 2010 which will make it difficult to perform this research. For the Netherlands the decrease of activated control power after participation in the IGCC has resulted in a settlement with control power of only 55% of the time. The rest is mostly settled with the IGCC although before the IGCC the amount of activated control power was also slightly less than the imbalance volume. A bigger control area due to participation of more TSOs will result in even less control power usage and therefore even more savings.

The decrease in control usage results in a smaller market for ancillary services. This market is thought to be interesting for DR in order to settle imbalance automatically. Since the IGCC also settles imbalance automatically, this market has decreased even with an increase of imbalance volume. Since more countries are expected to participate in the IGCC this market will get smaller and the incentive for DR for balancing purposes will therefore become smaller as well.

12. ANALYSIS OF THE IMBALANCE PRICE OF THE THREE COUNTRIES

IMBALANCE SETTLEMENT PRICES IN SPAIN

In Figure 28 the prices for control power and the spot prices are shown. The price for positive control power is higher than the price for negative control power. What can be seen Figure 28 is that the price for positive control power are very close to the spot price.

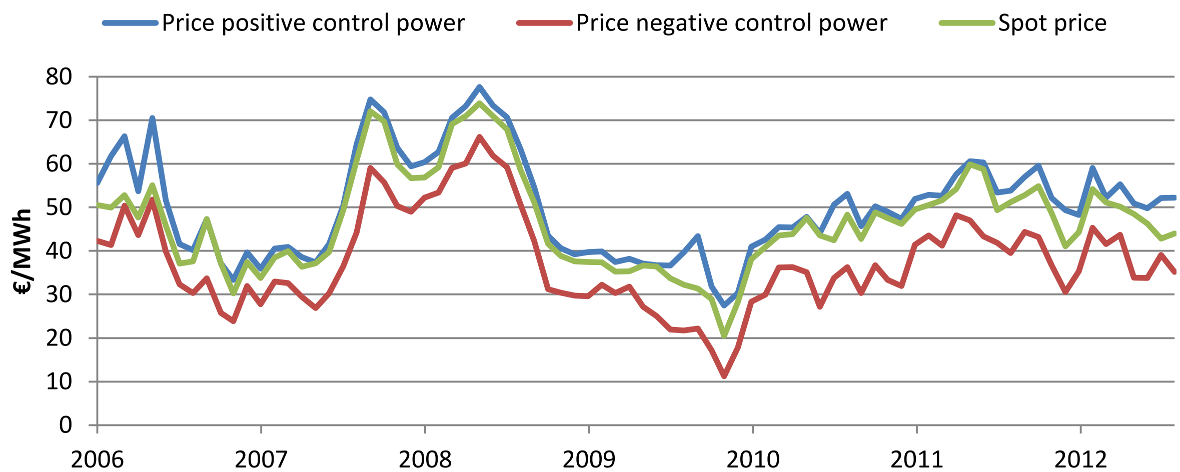


FIGURE 28: MONTHLY AVERAGE PRICES IN SPAIN

To find the actual imbalance settlement prices, equations 1 and 2 have to be used which were described in chapter 9 under ‘pricing’. These calculations provide an insight in the actual settlement prices as other impacts can also change the prices. By calculating the difference with the spot prices, the actual prices for control power is found.

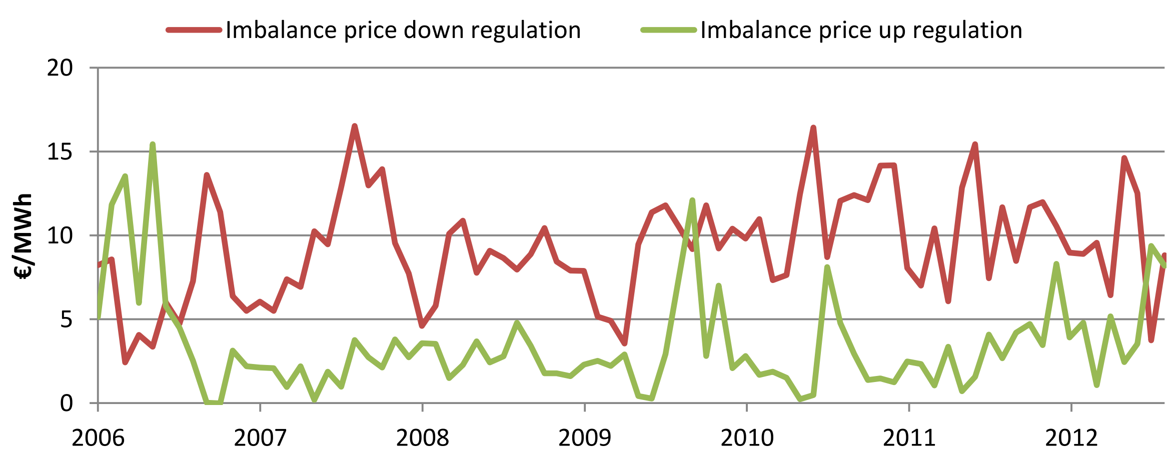


FIGURE 29: MONTHLY AVERAGE IMBALANCE SETTLEMENT PRICES IN SPAIN

In Figure 29 the price for imbalance is shown in which the price for up regulating power is higher than the price for down regulating power. There is an increase in the price for up regulation over time. For down regulation the price was higher than the price for down regulation before 2007. But even though the imbalance has increased, the imbalance settlement price does not show a large increase.

IMBALANCE SETTLEMENT PRICES IN THE TENNET CONTROL AREA

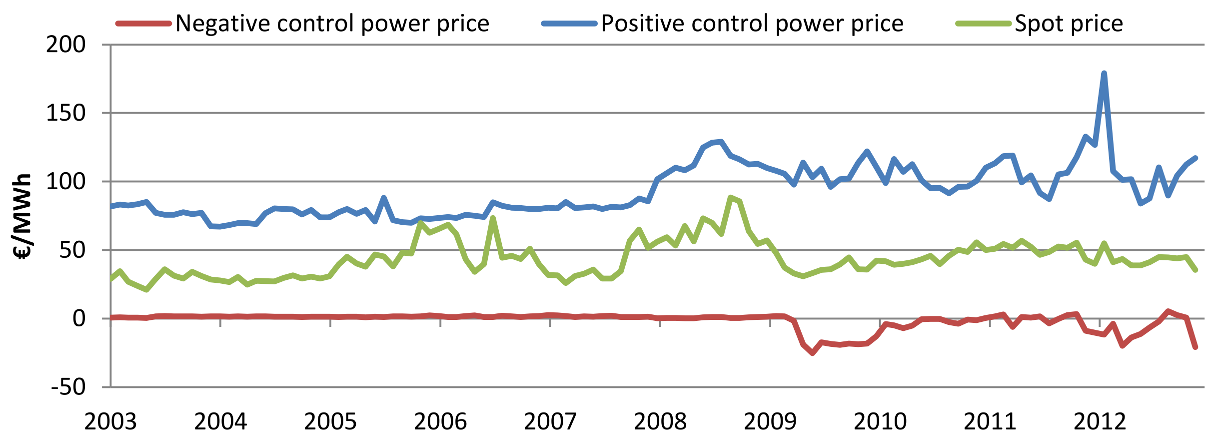


FIGURE 30: MONTHLY AVERAGE PRICES IN THE TENNET DE CONTROL AREA

In Figure 30 the price of imbalance is given for both positive and negative imbalance. After 2009 negative prices are allowed which clearly results in negative prices in the graph. To find the price for settling imbalance the calculation as explained by using equation 1 and 2. In Figure 31 the cost €/MWh are shown, it shows that both prices per MWh have increased until 2009 after which a slow decline is found which stabilizes after 2011. A higher price means a higher incentive for the BRPs to balance their portfolio, as it is the difference between the spot price and the imbalance price. A higher price can be the result of higher imbalances as

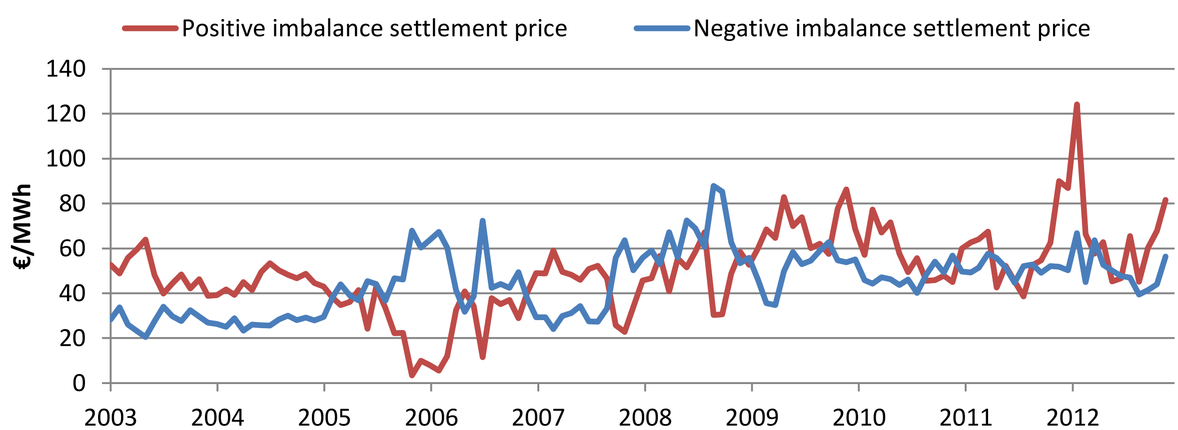


FIGURE 31: MONTHLY AVERAGE IMBALANCE SETTLEMENT PRICE IN THE TENNET CONTROL AREA

What can be seen in Figure 31 is that the positive and negative imbalance price seem to have an inverse correlation. When the positive imbalance price is higher, the negative imbalance price is lower and vice versa. Since the price goes up when more imbalance is found, this probably indicates that for this period the imbalance in one direction was dominant. This inverse correlation seems to decline after 2008 which can be the result of the GCC. It is also stated that the same settlement prices are used when the GCC started, there are however different prices published by the different TSOs.

IMBALANCE SETTLEMENT PRICES IN THE 50 HERTZ CONTROL AREA

Also for the 50 Hertz control area the prices area analyzed together with the spot prices. The spot prices are equal everywhere in Germany and therefore the same as for the Tennet DE control area.

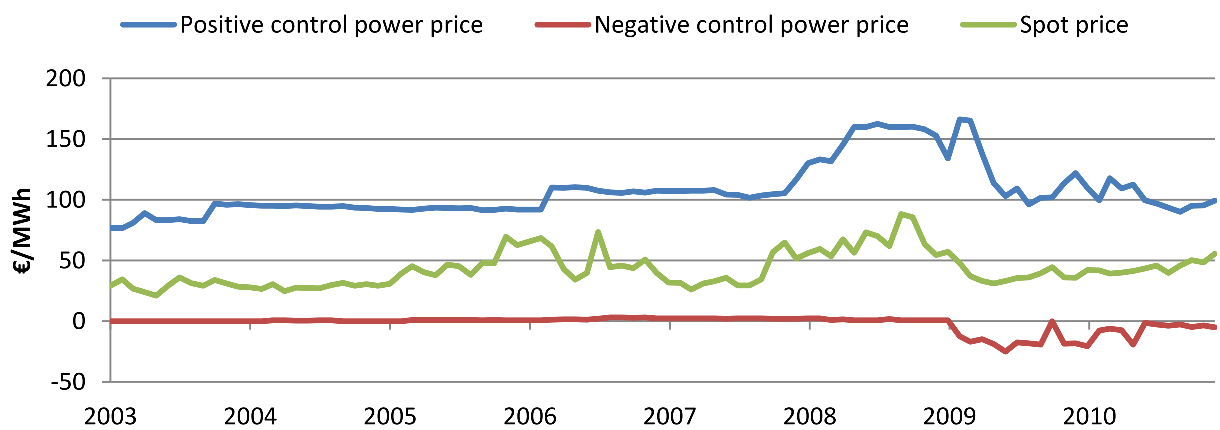


FIGURE 32: MONTHLY AVERAGE PRICES IN THE 50 HERTZ CONTROL AREA

In Figure 32 the prices for control power and the spot price in the 50 Hertz control area is shown. The calculation for the imbalance settlement is done by using equations 1 and 2 again resulting in Figure 33.

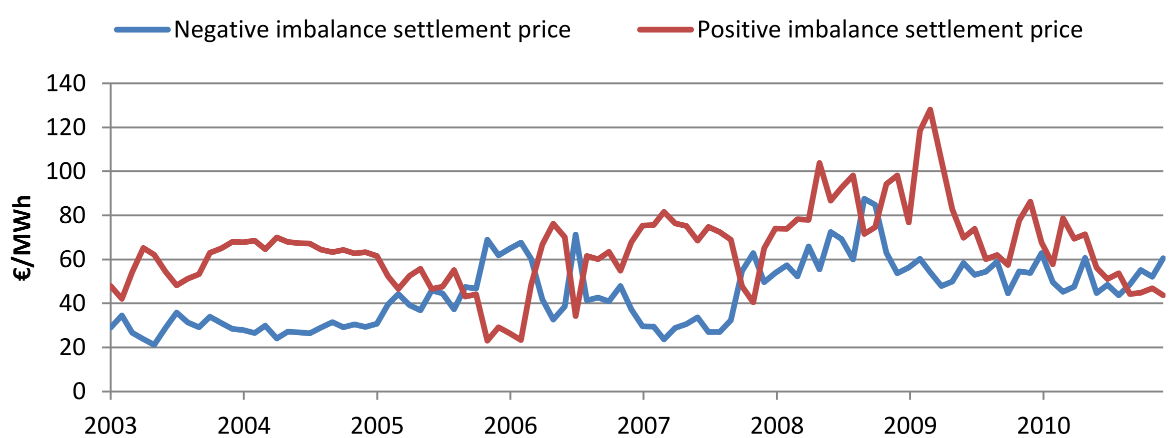


FIGURE 33: MONTHLY AVERAGE IMBALANCE SETTLEMENT PRICE IN THE 50 HERTZ CONTROL AREA

From Figure 33 it is found that the price for imbalance settlement have increased. This increase in price of imbalance settlement is a bigger incentive for BRPs to balance their portfolio. The graph shows that the positive and negative price show an inverse correlation; when one is high, the other one is low. This is likely to be the result of the amount of imbalance. A high positive imbalance results in a high price, when there is positive imbalance, there is probably less negative imbalance. This was also found in Figure 17 which is most likely the reason for the prices to show the same correlation. After 2009 the imbalance settlement prices decrease again which is likely the result of less demand for control power due to the GCC.

IMBALANCE SETTLEMENT PRICES IN THE NETHERLANDS

A similar graph is made for the Dutch prices, in which it is found that the spot price is in between the positive and negative control power prices.

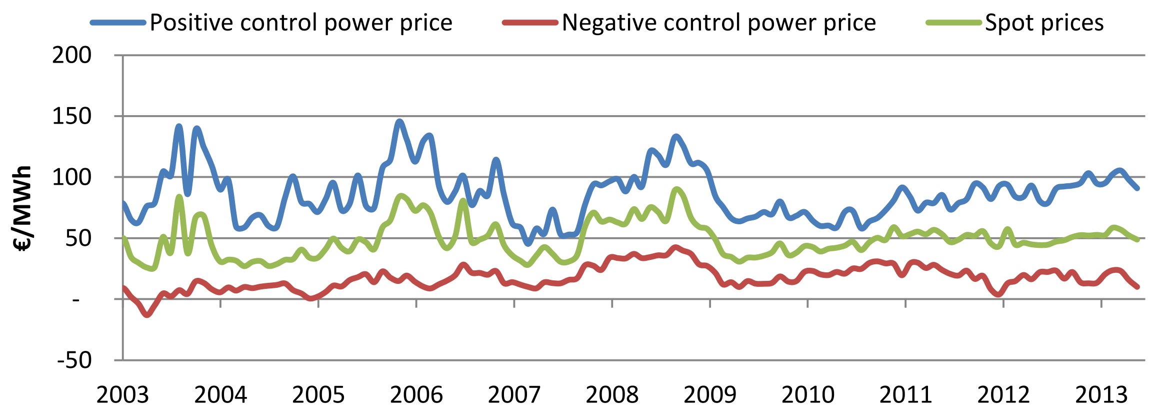


FIGURE 34: MONTHLY AVERAGE ELECTRICITY PRICES IN THE NETHERLANDS (TENNET)

Figure 34 shows that the prices for control power are much different than the spot prices. In the Netherlands the spot prices deviate more than in Germany where the spot price seems to fluctuate less. The same is for the control power prices, but they are dependent of the spot prices. This is why equation 1 and 2 are used again to calculate the settlement prices.

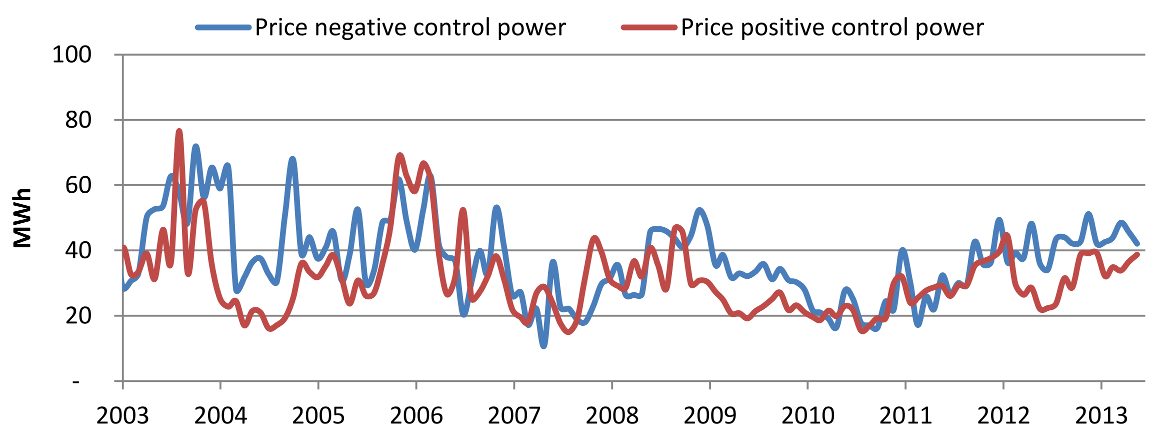


FIGURE 35: MONTHLY AVERAGE IMBALANCE SETTLEMENT PRICES IN THE NETHERLANDS (TENNET)

Figure 35 shows the imbalance settlement prices which are relatively equal. Before 2009 the prices are higher and after 2011 they increase again. The impact of a decrease in control power activation is not noticeable in the settlement prices yet as the prices slightly increase after February 2012.

CONCLUSIONS

IMPACT OF SUN AND WIND GENERATION ON THE IMBALANCE

From the data of the German and Spanish market it is found that an increase of VRES installed seems to result in an increase in imbalance volume. The imbalance volume has increased with a higher share of VRES installed in the different control areas in Germany and Spain. This increase is very noticeable and creates a less stable grid which needs more balancing actions.

It is found that the share of wind and solar installed capacity of the total installed capacity gives an insight in the boundary when an impact on grid balancing is noticeable. With a share below 20% of total installed capacity, the imbalance share of total consumption does not increase. When more than 20% is installed however, an increase of imbalance share is noticeable. Therefore it can be expected that for other countries, the share of imbalance will increase when more than 20% of installed capacity is from wind and solar generation.

The imbalance settlement prices in Spain are much lower than the prices in Germany. Since the imbalance is at a similar level and the spot prices have a similar value it is expected that settlement prices are equal as well. The price for positive control power are almost similar to the spot price in Spain. This seems to be the main reason why the prices for imbalance settlement are much lower for Spain than for Germany, especially for up regulation. Although the prices vary a lot in Spain, the price for down control power has increased. The big spread in price shows that there is a large but unpredictable market for control power in Spain. It must be noted that in Spain there is no IGCC to settle the imbalance, if this would be implemented the market would most likely change.

It is found that the volume in the Netherlands is lower than in the other countries. The share of 1% of imbalance of the total consumption is much lower than for Germany and Spain. Also the spread is much more stable than the other two countries with only small deviations. As these deviations are mostly yearly and are caused by changing consumers to other BRPs the Dutch grid is found to be very stable. The Netherlands is the only country with real-time control signals, it is possible for parties to participate on imbalance and therefore 'passively' balance the grid. This can result in large profits as the control power prices are much higher than the spot prices. This real-time publishment of the control signal is thought to be the main driver of the low imbalance in the Netherlands.

In the Netherlands the imbalance volume shows a small increase in the last years. This increase is most likely not due to the amount of VRES installed as this share has even decreased in the last years. The share of installed wind and solar capacity has stayed far below the 20% turning point so this should not have a noticeable effect.

For the prices of imbalance settlement it is found that the prices in Germany increased when the imbalance increased. After 2009 however the prices declined which is most likely the result of a decrease in control power usage activation.

It can be assumed that settlement prices increase when a higher demand for control power is found as cheaper control power is activated first after which more expensive control power shall be used. When more control power is needed, the costs will not only go up because more control power has to be paid, the price of the control power is also higher (Veen, Abbasy, & Hakvoor, 2009). It is found however that there is no large increase in prices in Germany and Spain. The prices only slightly increase which gives a bigger incentive for the BRPs but there is no large increase resulting in high payments. A decrease in control power activation also resulted in a decrease in settlement prices in Germany.

IMPACT OF CONTROL AREA SIZE

Imbalance is usually settled by activating control power. Since the GCC has started however, the amount of secondary control power activated has decreased even with higher amounts of imbalance volume. In the graphs it is clearly shown that before the GCC became operational, the imbalance volume and the amount of activated control power were about equal. After the GCC started operating the imbalance volume kept increasing while the amount of activated secondary control power decreased. For a large part of the imbalance volume, no actions were taken since it could be settled by the GCC, as a result only 35% of the imbalance volume was settled with control power.

After the participation with the IGCC, the amount of control power activation in the Netherlands has decreased which shows a similarity with the German TSOs. Only 55% of the imbalance volume is settled with control power which leads to the conclusion that most of the other 45% is settled with the IGCC. This results in a large decrease of control power costs and therefore a smaller market for control power. When more countries will be implemented in the IGCC, this is expected to result in a smaller share of imbalance settlement with control power activation.

13. DEMAND RESPONSE

WHAT IS DEMAND RESPONSE

When the grid has not balanced its generation and consumption, the TSO uses control power to reset the balance. The amount of generation is adjusted to the needed level in order to meet consumption. This can be either a generator which is able to generate more/less electricity within a short period of time but this can also be done with a consumer which consumes more/less within a short period of time. When the consumption is controlled, it is called Demand Response (DR). The Federal Energy Regulating Commission defines DR as follows: 'Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.' DR is part of a bigger system to make the grid more flexible which is called Demand Side Management (DSM)

Already in the 1980's DSM was widely discussed as a potential way to consume energy on a more efficient way. Peak shaving by changing consumption to moments when less power is consumed is generally seen as a better way to lower the peak load. And recently, the potential for implementing more VRES has been a motivator for DSM as well. Since many countries work with different definitions of DSM, the International Energy Agency refers to DSM in their IEA DSM program[3] as 'all changes that originates from the demand side of the market in order to achieve large scale energy efficiency improvements by deployment of improved technologies' (IEA). DSM therefore also includes DG like solar panels, this research focuses on DR in households to see what the impact can be for imbalance settlement.

POTENTIAL OF DEMAND RESPONSE IN HOUSEHOLDS FOR GRID BALANCING PURPOSES

DR is widely discussed as a way for peak shaving but it can also be used in balancing supply and demand. This can be done by managing the demand quickly so that less control power is needed. There are several devices and consumers which are suited for this which makes that there is a large potential. The potential for households is studied in this report in which the comfort of living should not be harmed. This can only be done for several devices when individuals will not notice it. For instance when there is a surplus of electricity and the freezer is not at its maximum temperature yet but will be activated to cool. The demand can be changed instantly when there is a deviation from the energy program. Imbalance can be settled automatically if an incentive is available for the device to respond. For domestic appliances there are two groups which can be used for DR (Rijcke, Vos, & Driesen, 2009):

- Appliance operating daily for a certain period of time.
- Appliances that are constantly standby and switch on or off.

[3] The IEA Demand Side Management program started in 1993 and develops and promotes tools and information on demand-side management and energy efficiency. The program is collaboration between 15 countries from Asia, Europe and North-America. More information can be found on http://www.ieadsm.org/Home.aspx

For the first group, it immediate control is less interesting a short period in time when imbalance is found. Appliances which are standby constantly can be used for balancing in some cases. These are appliances which can be switched on and off without affecting the comfort of the consumer. This can for instance be a freezer which generally has to keep the temperature below -18°C. This is done by cooling until -22°C after which the temperature slowly increases. This means that the power demand is in blocks which are on and off. When the freezer is cooling down but is at -20°C and there is not enough power generation, it is possible to stop cooling. This way the grid can restore its balance and when the freezer is at -18°C it will cool down again. This can also be done when a freezer is turned on, this way it can be seen as storage since it would need the power in the future anyway. This would result in a settlement of imbalance and therefore a decrease in control power usage. The potential of DR in households for grid balancing might only be a couple of devices per household. These devices cannot be used the entire time and are limited in its time to use.

DEVICES

For balancing actions of the grid devices need to have certain properties. To provide ancillary services with DR, the response has to be quick. Devices with a delay are suited in order not to influence the comfort of living which is an important factor of the success of demand response. These devices are also limited in the time that they are activated or deactivated as they usually do not have a constant load profile but it varies over time.

When a power plant failure occurs and less energy should be consumed, a possibility is to turn off all the freezers in households. Freezers are programmed to switch on when their inside temperature reaches -18°C and switch off when their temperature reaches -22°C. As they are all at a different spot of the temperature curve, they will all reach the -18 degree at a different time. This gives the possibility for a quick response as an ancillary service, but the capacity will slowly decrease. It will however buy enough time for other systems to provide (part of) the control power and at some moments positive control power is needed while negative control power is needed at other times. As a result the devices will have the flexibility to adjust to the needs over a longer period.

Since all freezers will activate and deactivate at the same time resulting in a big increase or decrease of the load curve but they will switch back again when needed for its own purpose, they will all stay operational for a different part of the load curve. It does mean that some power otherwise would have been used is delayed, like is done with peak shaving. In Figure 36 the different curves are shown of an empty and a full refrigerator. This curve is also influenced by human behavior which changes over the day and appliance which means that it will not be possible for all freezers to get in the same load curve meaning that they would all switch on at the same time.

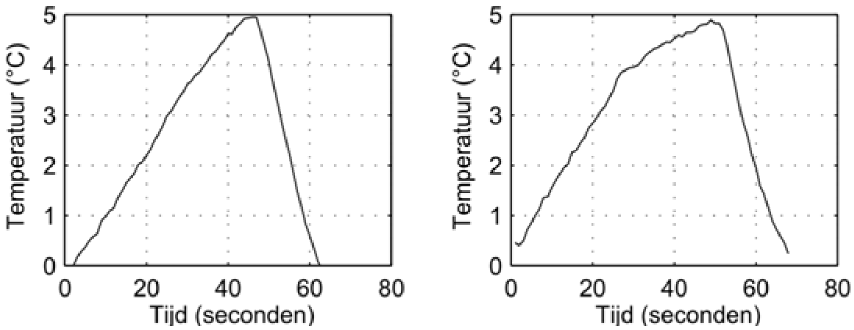


FIGURE 36: TEMPERATURE CURVE OF A REFRIDGERATOR (EMPTY AND FULL) (FLEXINES)

The appliances in households that are suited for ancillary services are:

- Freezer;
- Refrigerator;
- Electric water heater;
- Heat pump;
- Air conditioner

For this research the power use of these appliances is found after which their potential for demand response is estimated.

HOUSEHOLD APPLIANCES

FREEZER:

In the Netherlands 54% of all households owns a freezer which uses about 5% of the total power usage of the household (Energiezaak, 2011) (ECN, 2012). A freezer switches on and off automatically ranging in temperature between -18°C and -22°C. The result is an operating time of 20 – 35 % while the rest of the time it does not cool and does not use power. The annual consumption of a freezer is about 414 kWh which results in about 142 W_e (Stamminger, 2008).

REFRIGERATOR:

As there are 7,5 million households in the Netherlands, in which most households own a refrigerator. Since some households also own multiple refrigerators, 7,5 million refrigerators are used for this calculation. With an operational time of 20 – 35% and 50 – 300 Watt electrical power usage it is a big consumer of power in households. For refrigerators, human behavior makes a big difference on its power usage. The average annual power consumption of a refrigerator is about 403 kWh (Energiezaak, 2011) (Stamminger, 2008).

ELECTRIC WATER HEATER:

In the Netherlands there are 700.000 electric water heaters in households which use approximately 2.700 Watt electric power standby to maintain the warm temperature in the boiler. The use of hot water very much depends on the household and season. In the summer the hot water usage on a weekday is about 41 l/person/day while in the winter this is 51 l/person/day which can go up to 60 l/person/day on a Sunday (Stamminger, 2008). An electric water heater is usually programmed to heat water at night when lower electricity prices are used than during the day. Water is heated at night and depending on the boiler either cools down during the day or it maintains its temperature. When prices would fluctuate and there would not be a night and day tariff anymore this pattern would change dramatically. The power usage than highly depends on the hot water usage of the household; this results in very low power usage at night and peaks in the morning and afternoon when more hot water is being used.

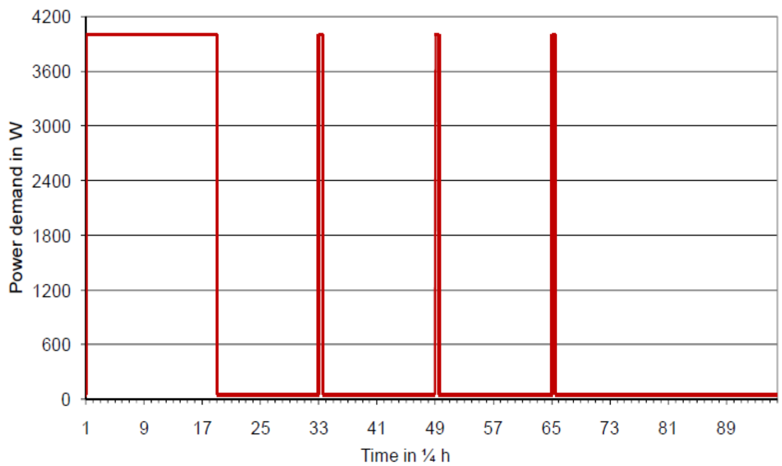


FIGURE 37: GENERAL PATTERNS OF A DAILY LOAD CURVE OF A 4 KW WATER HEATER OPERATING AT NIGHT AND MAINTING ITS TEMPERATURE DURING THE DAY (STAMMINGER, 2008)

For this report the power usage of an electric water heater which heats up at night and maintains its temperature during the day is used as this is the current situation. This model is mostly used in Western Europe. The advantage of electric boilers is that they have a big down regulating potential at night while most appliances have most of their down regulating potential during the day when people are at home. This results in more down regulating potential at night and more up regulating potential during daytime.

HEAT PUMP

Within the Netherlands there are 120.000 heat pumps installed of which 50.890 in households. The installed capacity is a lot lower for households, which is about 150 MW_e in 2010 (AgentschapNL). It is estimated that this will be a lot more in 2020 when 500.000 installed heat pumps will be installed with a power of 1.500 MW_e (DHPA, 2013). This can result in a large load which can be used to balance the electricity grid as there is a reservoir with water which is not affected immediately when no power is used for a short period. The heat pumps are not used all day as their power consumption during the day is about 1 kW and less at night. This results in about 50 MW of power which can be used for balancing services during the day.

AIR CONDITIONING

Domestic air conditioning is not used much in the Netherlands; about 2% of the Dutch households have an air conditioner installed. This is still about 150.000 air conditioners in the households which can be used for balancing purposes. Same as for heating, the number of cooling days in the Netherlands can be calculated using ´cooling degree days´. The calculation is similar, the equation for cooling degree days is:

$$Z(d) = \frac{G}{(t_z - t_i)}$$

In which:
Z(d)= number of degree days
G = number of heating degree days
T_i= inside temperature (18 degrees)
T_z= average outside temperature

For the Netherlands there are 12 cooling days, which does not give a large potential for balancing with DSM for air conditioning. There are however also days when the average temperature does not exceed the 18 degrees but there is still some cooling demanded. This is why for some countries especially in northern Europe the amount of cooling days is found by the World Resources Institute. For Belgium this is 102 while this is 66 for the Great Britain (Stamminger, 2008). In this research 90 cooling days are used for the Netherlands in which the air condition was operational for 6 hours.

TOTAL HOUSEHOLD POTENTIAL IN THE NETHERLANDS

Not all the appliances are in operation all day at their maximum capacity and mostly during the day more power is used than at night. There are also some seasonal differences which will result in deviations in the power consumption of the devices. An air conditioner cannot be used in the winter for DSM and the heat pump will not be used during summertime. This is why operating days are used to get a better understanding of the yearly potential of some devices. Only the freezer and refrigerator are appliances which can be used all day and year round. In Figure 38 the potential is shown in the summer and winter for up regulation and down regulation. This is dependent on the operational time of the device, for a refrigerator this is 33%. Of course the operational time is also dependent on human behavior and characteristics of the device. It is found that there is more up regulating potential than down regulation potential which is the result of less than 50% of load hours for most devices. Still there is a large potential for down regulating of more than 100 MW and a potential of up regulating of more than 200 MW. This is a large capacity for regulating services and can result in a serious decrease of secondary control power use in the Netherlands. The power usage of appliances that are applicable for ancillary services is found as follows:

TABLE 7: POTENTIAL CAPACITY FOR ANCILLARY SERVICES IN HOUSEHOLDS IN THE NETHERLANDS IN MW

Potential in MW	Summer		Winter	
	Up	Down	Up	Down
Freezer	41	-20	41	-20
Refrigerator	70	-35	70	-35
Air conditioner		-20	-	-
Electric water heater	97	-29	97	-29
Heat pump	-	-	14	-37
Total	**208**	**-105**	**222**	**-121**

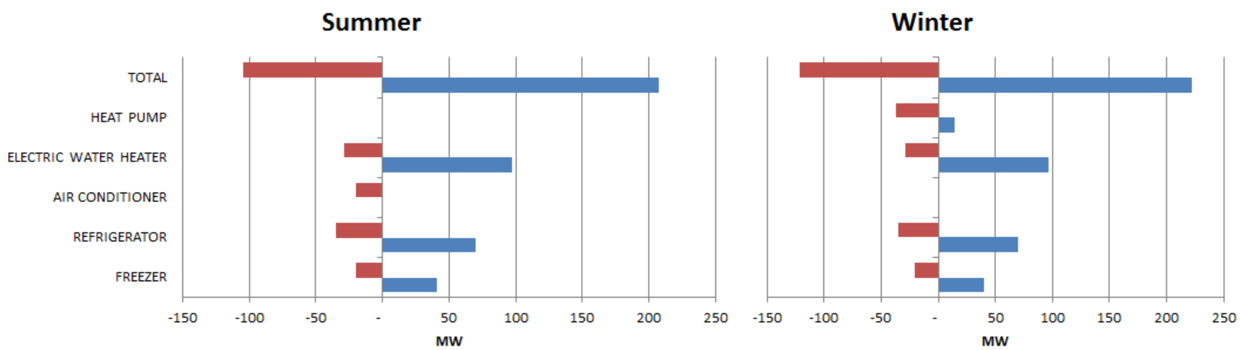


FIGURE 38: CAPACITY POTENTIAL DEVICES OF HOUSEHOLDS IN THE NETHERLANDS

This is a relatively high potential especially for the Netherlands as the absolute imbalance is around 110 MW. The potential per direction of regulation is different, there is generally more potential for up-regulation than there is for down-regulation. DSM is able to settle the imbalance for a large share. Secondary control power is needed as well for some cases, but it can be decreased for a large part. This will result in less expenditure on control power which can result in a decrease of electricity prices in the future.

DECREASE IN IMBALANCE COST

In order to estimate the imbalance cost of intermittent generation it is difficult to find the costs. Deviation from predicted generation caused by the VRES has to be analyzed per PTU as it can also 'passively' help settle the imbalance. In this case the BRP will receive a payment. When the deviation from predicted generation is in the same direction of the imbalance, a payment has to be made. Therefore it is difficult to find the actual costs of imbalance caused by VRES. For the decrease of a large amount of imbalance, this will however also result in less contracted power. The contracted power is dependent on imbalance based on historical figures and is more than the actual used balancing power. By only calculating the cost for balancing power it will result in useful numbers for relatively small amounts of imbalance. When large amounts of imbalance cost have to be calculated, contracted reserve power also has to be included in the costs. If the imbalance has decreased by a reasonable amount, there will also be less contracted reserve power. This will result in lower costs above the decreased costs of activated energy. Although the largest part of the costs is for activated control energy, which also depends on the settlement price but it will make a difference. As the settlement price is based on the bid ladder, a decrease in imbalance will also result in a decrease in settlement price. This makes a calculation in decrease of imbalance cost difficult as the residual imbalance will be settled by a lower price.

All these factors make it hard to estimate actual decreased costs. In Figure 39 the annual revenues for maintaining the energy balance are shown. These are the costs made by the TSOs for balancing services which will be paid for by the BRPs which caused imbalance leading to zero balancing costs for the TSO. The costs for separate parties might be higher but these costs are the costs for society. If the total imbalance would be regulated by smart appliances these will be different. Since DR from smart appliances will also have its price, the amount of savings will determine whether implementation of smart appliances will result in overall savings.

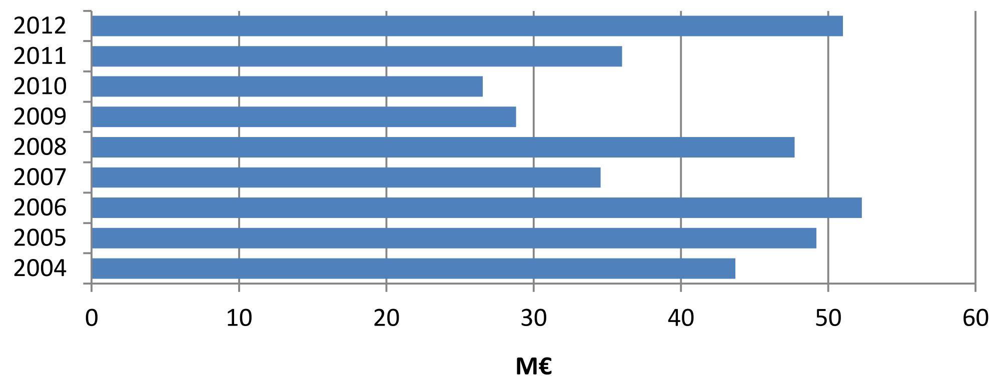


FIGURE 39: YEARLY IMBALANCE COSTS IN THE NETHERLANDS (SOURCE: ANNUAL REPORTS TENNET)

The average total absolute imbalance in the Netherlands was around 110 MW in 2011 as found in Figure 23 from which a large part could be settled with DSM in households. Figure 38 shows that there is a potential of more than 100 MW down regulation and more than 200 MW up regulation throughout the year. The imbalance can be settled with DSM in households as the imbalance volume in both direction is about 55 MW.

For savings of regulating power this can result in a decrease in cost of more than 30 M€ annually. This would however mean that households will have to install smart appliances. The idea of an electricity company to regulate the power usage of a device in your house is still something which has to be accepted by people. One incentive could be money, even when the comfort of living is not influenced. Lower balancing costs would result in a decrease in electricity prices which is an incentive for implementing smart appliances in a household. A decrease in imbalance costs of 30 M€ results in an average decrease of €40 per household. These costs savings are limited, but it results in a lower electricity price without any comfort decrease and can therefore be enough for some people to participate.

DEMAND RESPONSE IN THE NEAR FUTURE IN THE NETHERLANDS

It is found that the imbalance in the Netherlands is likely to increase when more than 20% of the total installed capacity is from VRES. The Netherlands will increase its share of renewable energy sources (RES) which can affect the stability of the grid. Until now, a relatively low share of RES has been installed in the Netherlands but this is expected to change. As a result, the increase of imbalance due to VRES is thought to be settled with smart appliance in a so called 'smart grid'. As found in this research the imbalance does not seem to increase until a share of more than 20% of VRES is installed. In the Netherlands the goal for 2020 is 14% of RES of total energy usage from which not all the sources will have a variable output and not all will be electricity. So an increase in imbalance due to the installed capacity of VRES will not be reached before 2020 and will most likely take some more years until this boundary will be reached for the Netherlands

An increased volume of imbalance does not necessary result in an increase in activated control power. With interconnections, the neighboring TSOs can settle imbalance of opposite direction across borders in the IGCC. As a result, the control power market in the Netherlands is likely to decrease instead of increase. Less control power will be traded which results in a decrease of the market size. A decrease in control power activation will also result in a decrease of the imbalance settlement price. The price has risen due to more demand of control power; cheap control power shall be used first so a decrease in control power demand will result in lower settlement prices. This will give a lower incentive for implementing smart appliances as it will not be necessary for balancing purposes in the near future.

Additionally there are also ways to settle imbalance with VRES by operating them at only part of their potential. The output can be controlled as generation is not at is maximum and can therefore be in- decreased. This will result in a lower overall output, so less electricity is generated and therefore some energy is 'wasted', but it does result in a lowering cost for connecting wind and solar power to the grid. Together with the social discussion about the privacy and freedom when DR is implemented, it can take some time before DR in households will be implemented on a large scale. For the upcoming years however this is not necessary for balancing purposes yet when TSOs will cooperate and balance the grid together.

14. CONCLUSIONS

Different influences on the imbalance of the electricity grid have been investigated. Main concern for this research was how the imbalance will change in the Netherlands in the near future. What is believed to have a large impact on the imbalance market is the increased amount of installed VRES. What has been found in this research by studying the data from Germany and Spain is that the imbalance volume has indeed increased with the implementation of more VRES. By looking at yearly data of the countries together with their share of installed VRES it was found that below a share of 20% of installed VRES the imbalance volume did not increase. When the share of installed capacity VRES was higher than 20%, the share imbalance of the consumption was found to increase for several control areas. The major conclusion of this research is that the imbalance share increases due to VRES when the amount of installed capacity VRES is more than 20% of total installed capacity.

The increase of imbalance volume is expected to create a huge market for ancillary services and other imbalance settlement designs like smart grids. In Germany the four TSOs have started a cooperation to settle imbalance by the German Grid Control Cooperation (GCC). Two neighboring control areas with opposite imbalance can settle imbalance with each other, instead of purchasing control power. An interconnection between the two control areas creates the possibility to settle (part of) the imbalance from opposite directions. This results in less activated control power and therefore lower settlement expenses. After the implementation of the GCC, an immediate decrease of activated control power is found despite the increase of imbalance volume. The participation of neighboring countries of Germany resulted in the International Grid Control Cooperation (IGCC). As a result it was found that for the Netherlands, same as for the German TSOs, the activation of control power decreased after participation with the IGCC. This resulted in a decrease of the market for ancillary services. An increase of the IGCC is expected to result in a higher decrease of the share of imbalance settled with control power.

Before the IGCC an increase of activated control power was found. Together with this increase it was found that the prices for settling imbalance also increased. Since cheaper control power will be activated first, an increase in control power usage will automatically lead to an increase in price. This increase of the prices is found for the German TSOs but this correlation was found less for Spain. An explanation is the low additional costs for positive control power in Spain which is only slightly higher than the spot price. As a result there are less additional costs for imbalance as the settlement price is based on the difference of the control power price with the spot price. In Germany it was also found that when the IGCC was implemented and the control power usage decreased, the price decreased as well.

The potential in households for ancillary services is calculated in order to estimate if the increase in imbalance can be settled with Demand Response (DR). Since the comfort of living should remain equal, suitable devices are limited. The potential for both up- and down balancing are calculated for the summer and the winter and it is found that throughout the year there is 100 MW of down regulation and 200 MW up regulation available in households in the Netherlands. The current absolute imbalance is around 110 MW, the potential of DR in households is promising. However the costs for balancing are only around €40 per household annually which gives a low incentive for the implementation of smart appliances for balancing purposes. The market, which was expected to increase due to increased imbalance from VRES, will even decrease in the next years because a large part of imbalance will be settled with the IGCC. This gives a low incentive for the implementation of smart appliances for balancing purposes. It can however still be interesting to implement smart appliances for other purposes than grid balancing.

The imbalance in the Netherlands is relatively low compared to other countries. It is found that the Dutch imbalance share of consumption is much lower than that from Germany and Spain. This is most likely the result of the real-time data which is published by the Dutch TSO Tennet. This provides the possibility to react to imbalance and therefore help ‘passively’ balance the grid. Since the Netherlands is the only country in Europe that provides this service, this is thought to have a big impact on the low share of imbalance.

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APPENDICES

APPENDIX A

Data of the German TSO Amprion:

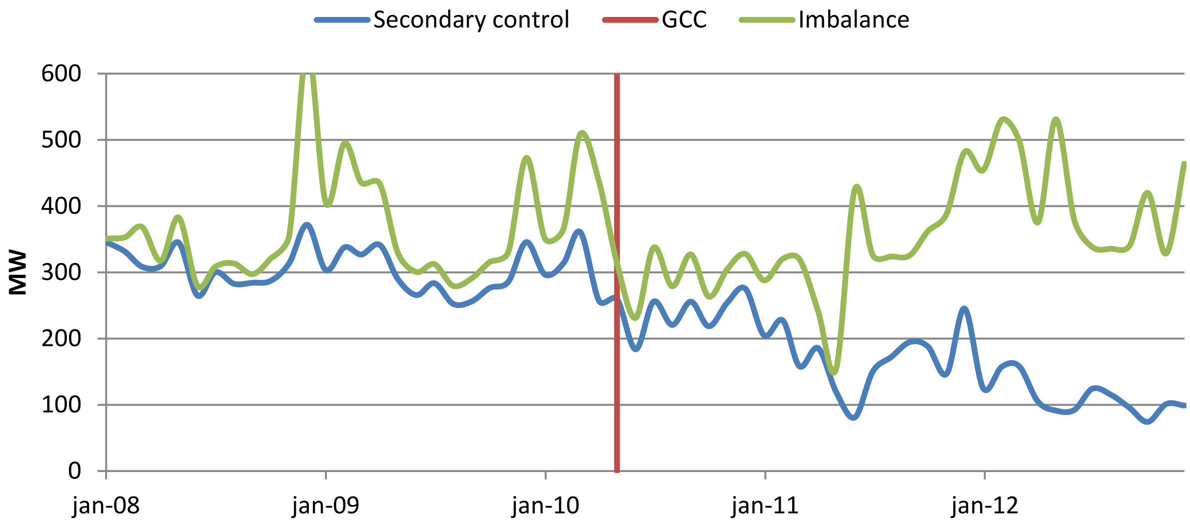

FIGURE 40: AVERAGE MONTHLY IMBALANCE VOLUME AND CONTROL POWER ACTIVATED IN THE AMPRION CONTROL AREA

Data of the Danish TSO Energinet for which only data of the West side has been preserved.

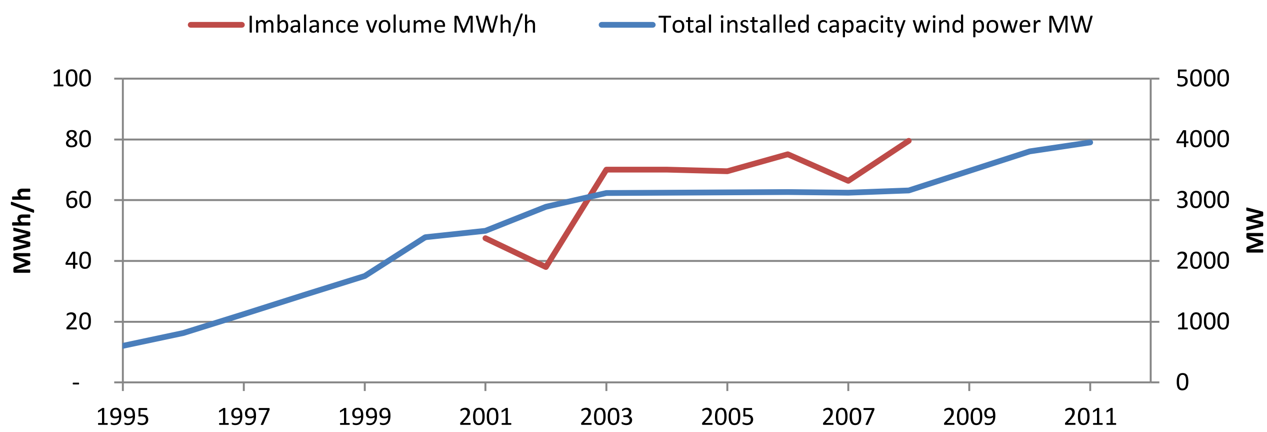

FIGURE 41: YEARLY AVERAGE IMBALANCE VOLUME TOGETHER WITH THE INSTALLED CAPACITY WIND GENERATION IN DENMARK WEST