ASSESSMENT OF SYSTEM ADEQUACY: A NEW MONITORING TOOL

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Summary: This paper describes the application of a new hybrid power & energy assessment method on system adequacy for both an all thermal and an all hydro system. It demonstrates the differences and the general applicability of the method.

1. Problem definition

The electricity supply system in the Netherlands was reshaped through the 1998 Electricity Act implementing the EU electricity guideline. Market parties are legally required to submit balanced energy programs, act accordingly and settle any imbalances with Dutch TSO TenneT. Other than that they are essentially free in forecasting, scheduling, commitment, dispatch and trading functions. TenneT is committed to comply to UCTE requirements of primary and secondary reserves. In the new Act responsibility for the long-term adequacy of supply in the Netherlands is no longer explicitly defined and assigned. Inadequate supply will lead to failure of the market and eventually failure of the system. Market failure occurs if market parties at gate closure have been unable to meet their obligations, thus maintaining implicit unbalanced programs, or to cope with outages of longer than the period of gate-closure. This will lead to higher demand on the real time balancing system. If the real time balancing demand can no longer be met, the rules of UCTE support are violated and, ultimately, load may have to be involuntary shed, indicating system failure.

On request of the Minister of Economic Affairs TenneT has started monitoring of the supply adequacy situation with the voluntary assistance of power generating companies to provide part of the necessary data. In the absence of centralized control, but given the functionality of Program Responsibility, TenneT has developed a robust method to identify market failure and system failure. An advantage of the model is that results can be easily checked against actual observations. To explore the broader applicability of the model, it was also applied on the 100% hydro Norwegian market.

2. Hybrid energy/power model

Traditional methods like LOLP require large amounts of data that are not available in the Dutch case because there is a considerable lack of completeness of power measurements on the generating side. TenneT operates only the highest voltage network (220 kV and up) and more than 70% of all generating capacity is connected to lower voltages, and up to 1/8th of domestic consumption comes...
from on-site production and is not transported over the public grids. For historical reasons and because of cooperation of most market parties TenneT observes 75% of total generation. For monitoring of long term security of supply TenneT receives direct information on a voluntary basis from 75% of the generating side. The rest of the necessary information must be added through other not for monitoring dedicated sources used for TenneT’s Capacity Plan.

Therefore TenneT developed a new assessment method. It does not focus on the eventuality of imbalance but rather on what is required to satisfy domestic requirements and to what extent domestic generating capacity is able to comply, given that system balance is required and will occur. So of interest is to identify commitments on domestic capacity resources that provide energy to the market. Section 2.1 identifies the different categories of resources that supply energy or capacity to the market. Section 2.2 assigns all commitments of the market onto the most important resource: commodity capacity.

2.1 Capacity categories

Commodity capacity is domestic generating capacity that is controllable and whose generating costs are highly correlated to the market price. Presumably this capacity runs for two thousand hours or more a year. System reserves (immediate reserves) can be provided from this capacity only. Operating reserves (intermediate reserves) may be provided from this category. Observability of this kind of capacity is fair.

Reserve capacity is defined as capacity of generating resources that is controllable and runs less than two thousand hours a year. This capacity will serve in the market mostly as operating capacity that will be started after some unforeseen event to provide for the intermediate shortage of supply resulting from these events. Once running it can also contribute to system reserve (immediate reserve). Observability of this kind of capacity is poor, since quite a lot may be hidden as dispersed resources.

Commercial Load Shedding. The Netherlands have a long demand side management tradition. Under centralized planning and dispatch some peak tariff systems have been in place which had effective incentives towards peak shaving and load shedding. However, this may lead to a decrease in some particular loads that may or may not include peak load, not to a decrease of yearly electric energy consumption. The reason is that demand side management is only efficient for larger customers who can afford the necessary investments to do so, mostly industries that just postpone their electricity demand to a later moment. So interruptable loads do not affect the electrical energy consumption of the system. It does provide however balancing capability.

Capacity from non-controllable resources. Wind energy and solar energy are examples of this type of capacity. Their characteristic is that they provide electric energy but can't be turned on at wish. Their contribution to the system is an energy contribution leading to less degree of usage of commodity capacity. Unknown yet is what an increase of these resources mean for the reserve requirements of the system. This needs to be further investigated.

Cross-border interconnectors. A difficult kind of capacity for adequacy assessment is import capacity. In itself it is no capacity that contributes to generation adequacy. Only if there is some degree of certainty that power will flow through this capacity it may contribute. In the Netherlands a part of the existing import capacity is occupied by long term import contracts. However these will end eventually in 2007. For the remaining import capacity an auction is in place. In this auction import capacity can be bought for no more than a year in advance. Without a clear international "system price" this makes it difficult for the market to establish new long term import contracts. It is however not impossible. The solution of this assessment problem is to handle import capacity not as an input parameter to the model but as an output. This will be explained later with examples.

2.2 Commitments on commodity capacity

The next step is to make a complete inventory of all commitments on electric energy that rest on or are assigned to commodity capacity and express these as utilization factor. A sum of commitments > 100% indicates system adequacy violation.
2.2.1 Energy demand

The yearly domestic demand of electrical energy is well known in TWh and forecasts are available from outside sources.

2.2.2 No-load

Definition

From a daily demand curve (Figure 1) the following characteristics can be observed:

- a solid black line indicating the average demand of the day. Available generating capacity that is equal to this average demand is able to generate the total daily electrical energy consumption, however because electrical energy can not be stored it can not supply the electric energy demand exactly when needed. Shortfall will occur in the period where the dark grey area supersedes the solid black line, whereas generation is not matched by demand on where the solid black line hovers over the dark grey area.

- a dashed line indicating the maximum demand of the day. Available generating capacity that is equal to this maximum demand is able to generate the total daily electrical energy consumption and it is able to exactly supply the electrical energy demand at every moment of the day. This dashed line defines a light grey area. Given generating capacity equal to the maximum demand, this indicates the minimum amount of energy that can be generated but that must not be generated because there is no demand for it. This light grey area is defined as the “no load” area. Thus no load is an energy commitment on installed generating capacity reflecting the load following requirements of the system.

Forecast of yearly minimum no-load

What is true for the daily load curve is also true for the sorted yearly load curve. This is displayed in Figure 2.

For an accurate and robust estimator of the yearly minimum no-load, chronological historical information on system demand must be available. In the Netherlands, system demand has never been completely observed. This constitutes a severe problem to any approach to assess system adequacy. Studies have shown however that an accurate and robust estimator of the yearly minimum no load is constituted by the 95 percentile value of the yearly demand curve (indicated in Figure 2 by a dotted line). This estimator is robust against different levels of completeness of observations of system load, different tariff systems, increase of total volume of observed system load and different accuracy levels of observations whereas an estimator based on peak demand is less accurate due to coincidence (peak demand is on a steep point in the load duration curve, 95 percentile value is on a sub-horizontal point), weather influences (a severe winter will increase peak demand, the probability that it will increase the top 5% of demand is small, if it does increase top 5% of demand it will most likely also increase the yearly electrical energy consumption), tariff systems (peak demand reductions vary under different tariff systems, reduction up to 350 MW has been observed) and voluntary load shedding. Which is shown in Figure 3.

Following an estimate of market size the no load requirements can be accurately derived from this relation. Recent enlargement of the observed share of the market seem to corroborate this as indicated by the 5 dots on the right of the figure. Actual market size is situated at the right end of the regression line, indicating the tremendous amount of extrapolation required to describe the Dutch system under any method.
2.2.3 Planned unavailability

Another commitment on commodity capacity comes from maintenance requirements. Each generator needs now and then some revision to maintain reliability and efficiency. There is some freedom in the amount of yearly maintenance and in scheduling of maintenance periods. The method only needs the total amount of yearly maintenance.

2.2.4 Unplanned unavailability

Unplanned unavailability is the result of forced outages. These occur due to the highly complex technical and mechanical nature of generating units and the natural wear and tear of the equipment due to rotation, high temperature pressures and the dynamic loading of the generators. Forced outages can sometimes be shortly delayed to overcome peak demand periods, whether this occurs should depend on the market price and the imbalance price compared to the damage costs incurred by the delay. This may influence availability at peak demand, on a yearly basis it is rather unlikely that it influences the total amount of unavailability due to forced outages.

2.2.5 Overlap

Due to different effects (season, type of day) in the load curve, daily peak demand may be lower than the 95 percentile value of the yearly load curve. This provides for some overlap possibilities between total unavailability of commodity capacity and minimum no-load. This overlap can be increased by better coordination of maintenance through-out the seasonal pattern of the load curve. Some overlap also remains from forced outages. However, overlap can not be observed and seasonal differences are small in the Dutch situation. Therefore overlap is conceptually not modelled. This consistently may lead to some overestimation of commitments on commodity capacity.

2.2.6 Synchronous operation requirements

The Netherlands is synchronously interconnected within the UCTE network. Therefore the Netherlands' system should comply to UCTE requirements. UCTE requirements put additional commitments on commodity capacity, 120 MW for primary reserve and 300 MW additionally for secondary reserve.

2.3 Example

A complete picture of all commitments on given commodity capacity at a given market size then looks like Figure 4.
The white area above the black point until the UCTE area is available free room on commodity capacity in this configuration.

2.4 Adequacy requirements

The market needs additional reserves to accommodate variations in forced outages that temporarily lead to higher unavailability than average, especially during peak hours. Also some reserve is needed because of the discrete nature of planned unavailability schemes.

The three area point where the marble area, the UCTE grey and the white area intersect is the highest point were the market can not be deemed inadequate. Thus, this three area intersection point defines a necessary condition for adequacy. Beyond this point the market will not be able to fulfil all it's commitments on commodity capacity alone, so there will be structural shortage unless energy from other resources is available that can reduce the utilization factor to below this point. These other resources may include reserve capacity, capacity from non-controllable resources and imports. Figure 5 shows the result for the Netherlands for 2001.

Commodity capacity alone (black dot) was not sufficient for adequacy. The required utilization factor is infeasible. The dark grey point just in front of the black dot reflects the reduction in utilization factor from the contribution of energy from non-controllable resources, the light grey dot shows the contribution from reserve capacity and finally the white dot shows the resulting utilization factor after contribution from imports. Since the market and the system have shown no balancing problems obviously the white point is somewhat below the required point for sufficient adequacy. But what is the exact point for sufficient condition for adequacy?

2.4.1 Sufficient condition

For balancing purposes, the Dutch TSO requires on average about 975 MW of spinning reserve on commodity capacity, from which also the UCTE secondary reserve obligations are fulfilled. Thus, as an estimate for sufficient condition 675 MW of free room on commodity capacity is used. This sufficiency requirement is valid under the current situation of installed capacity from non-controllable resources. However if substantially more of this capacity is installed additional reserves on commodity capacity will be required. How much more needs to be studied further.

3. Results

Using the above method, given information from generators and adding information from the prevailing Capacity Plan 2003-2009, the results for the Netherlands are as shown in Figure 6.

The results reveal an increasing import dependency. Further details can be found in the Dutch Monitoring Report Security of Supply 2002-2010 [1].
4. Applicability in the Norwegian case

Applicability of the assessment method is based on the assumption that given energy requirements can be met over the year, to meet (peak) power requirements throughout the year is a scheduling problem for the market. Necessary scheduling room must be available from: reserve power, load management, scheduling of overhauls and free (energy) room on commodity capacity.

To get a better idea of the general applicability of the method, an attempt was made to use it for the Norwegian case. The Norwegian generation system exists of practically 100 % hydropower, and together with the characteristics of demand, this creates a very different situation as will be shown.

4.1 Capacity categories

Commodity capacity is all domestic hydro capacity. In a hydro system, all generators make efforts to use all the water that flows to their reservoirs. Not to do so would be a loss of generation and revenue. Therefore, it is not meaningful to divide generation in commodity and reserve capacity. The load factor for Norwegian hydro generation is approximately 50 %.

Demand side management capacity is presently available through Statnett’s Regulating Power Option Market. This is pure reserve capacity, and does not contribute to reductions in energy consumption.

Capacity from non-controllable renewable resources. There is at present very little wind power available in Norway. A certain share of the hydro capacity is run-of-river, and can be regarded as a non-controllable resource – however, this distinction has not been made here.

Import capacity. Norway has comparatively strong connections with Sweden and Denmark, which allow for a considerable energy import. With respect to a peak situation, there is uncertainty about the availability of generation capacity in the neighboring countries. In Sweden, there will with great certainty not be any surplus capacity for export. Denmark normally has ample capacity, but there are uncertainties regarding wind generation, heat demand in CHP plants and demand from Germany.
4.2 Commitments on commodity capacity

4.2.1 No-load
The yearly load curve in Norway shows a very typical seasonal pattern, summer peak is about half of winter peak. Besides due to the application of electricity as the primary heating resource there is a strong temperature dependency on the total yearly consumption as well as on the peak demand. Available statistical data (1989-2002) was insufficient to determine a robust no-load estimator for different temperature scenarios. Modeling temperature as an endogenous variable revealed a significantly less robust estimator as in the Dutch case. For Norway for the period 1989-2002 the estimator of 95 percentile values of annual demand shows a coefficient of determination \(R^2\) of only 0.87 compared with 0.95 for a comparable period for the Netherlands. Demand above \(P_{95}\) varies between 1700 and 3400 MW with an average of 2650 MW or 14 \% of \(P_{95}\) against 5 \% of \(P_{95}\) for the Netherlands. For the purpose of this experiment consumption in January and February was modified for temperature variations, yielding a \(R^2\) of 0.97. The relation for the market demand and no-load is shown in Figure 7. Exogenous modeling of temperature was not studied.

4.2.2 Unavailability
For thermal plants unavailability mainly comes from overhauls and forced outages. Primary energy supply can be planned and scheduled to needs and can therefore be neglected as cause of unavailability. This is typically not so for hydro power. Primary energy supply is restricted to the yearly water inflow. The shortage of water inflow to use generating capacity fully throughout the year can be modeled as a commitment on capacity due to unavailability of primary energy.

Because of the low load factor and the considerable seasonal variation of demand, planned maintenance is almost entirely done outside the peak demand (winter) season. On the other hand, there is reduced availability in the winter season due to hydrological factors (11\%). The forced outage rate of hydro plants (1\%) is generally much lower than for thermal plants.

4.2.3 Overlap
Because of the highly seasonal load pattern in Norway, overhauls can entirely be scheduled during off-winter periods, giving 100\% overlap between overhauls and no-load. Forced outages during off-winter periods also overlap 100\% with no-load. Reservoir capacities are large enough to schedule lack of primary energy supply in overlap with no-load.

4.2.4 Peak demand
Energy consumption beyond the 95 percentile varies between 0.2 and 1.9 TWh for the Norwegian case for the years 1989-2002, with an average value of 0.9 TWh, a little less than 1 \% of total consumption.

4.2.5 Reserve requirements
The primary reserve requirements for Norway within Nordel are 513 MW. There is a recommendation to keep 1000 MW as secondary reserves, but in practice Statnett attempts to have close to 2000 MW available to handle unexpected high demand. Because approximately 1000 MW of these requirements come from demand resources, about 1500 MW is commitment on capacity from system reserves. Due to the typical load pattern most time of the year this commitment will coincide with no-load.

Figure 7: Norwegian no load estimators
4.3 Cold and dry year scenarios

The effect of a dry year can be expressed in additional "no primary energy" commitment on capacity without overlap with no-load. The effect of a cold year is two-fold. First, the market volume will increase due to the electric heating application and secondly the no-load will increase because winter-peak / summer-peak ratio will increase. The market volume effect can be deducted from statistical data. However, for the effect on no-load further study is necessary.

4.4 Norwegian result

Figure 8 shows the model result for the Norwegian system in 2003, with a total demand of 124 TWh. This was the actual demand in 2001, although demand in 2003 was as low as 115 TWh, primarily due to high prices because of drought and high winter temperatures. Energy consumption above the 95 percentile is modeled as a commitment on generation capacity. Under normal conditions the necessary condition for system adequacy can be met with an import of approx. 6 TWh. The deficit in a dry year is also shown as a conditional commitment on generation capacity. Should such a year occur, very high imports would be necessary. The figure shows a necessary import of 30 TWh, but this is seen as unrealistic by many observers. On the other hand, as recent experiences show, demand will be significantly reduced in long periods of high prices. With respect to extreme peak demand, a scenario with normal primary energy supply but extreme colds will be problematic. The market did show high prices and demand response in low primary energy supply situations, however price response (and thus demand response) due to extreme cold temperatures alone is more challenging, although efforts are being made to increase short-term demand elasticity.

5. Conclusion

This article has demonstrated the usability of a new system adequacy assessment method for an all thermal system as well as for an all hydro system. It is shown how the method provides insight into the minimum amount of energy that must be imported to guarantee system adequacy. Both the Netherlands and Norway show import dependency. The method can also be used to find the maximum amount of energy that can be exported before system adequacy is endangered. Although at first sight the method looks less promising for a hydro system, the problem for assessing such systems is that primary energy supply on the one hand and climatic conditions on the other hand need to be modeled as exogenous parameters. This problem occurs with any assessment method. It is illustrated however how different scenario's for these parameters can be expressed in terms of the assessment method, yielding a good understanding of the future overall electric energy/power balance situation.

6. References


Figure 8: 2003 results for Norway