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Combining Market Simulations and Load-Flow Calculations for planning of interconnected systems with high RES penetration – Practical Experience

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SUMMARY

The ongoing internalization of the European electricity market together with the growing penetration of renewable energy sources (RES), i.e. wind power and solar, require an internationally oriented transmission planning approach that considers the increased uncertainties in terms of trade, location of generation and output of intermittent generation. In order to tackle these challenges, our previous work proposed a round-the-year approach for identifying and ranking bottlenecks in the transmission grid. The method combines market simulations with security analysis, and uses a statistical risk-based approach for performing the ranking.

This paper brings the method a step further by implementing it on a real-life case study for a 2020 demand and supply scenario for north-western Europe, focusing on the Dutch power system. The market model has a larger perimeter (17 countries) than the grid model (5 countries) in order to more accurately reflect influences of generation, i.e. RES, and demand in the area outside the transmission grid planning focus area. In this paper the challenges and assumptions related to coupling the market and the grid models are explained. Running this method of combined market simulations and load-flow calculations for a real grid on a regular office computer is demonstrated. The results that were obtained with the round-the-year approach are compared to an analysis based on two snapshots of moments conventionally chosen in transmission grid planning for the same future scenario by TenneT, the Dutch TSO, in their 2011 Quality and Capacity Plan. The round-the-year analysis proves to give much more insight in the bottlenecks in terms of severity and probability of occurrence (the so-called risks of overload), and also in terms of sensitivities of grid elements to the evaluated contingencies. Moreover, an assessment of a network reinforcement strategy is demonstrated, i.e. increasing the rated capacity of one of the most congested grid elements. The security analysis and bottleneck ranking performed on the upgraded grid structure and using the same market simulations results, shows the degree of reduction in the congestion of that particular branch and the overall reduction in congestion.

KEYWORDS

Transmission planning, round-the-year approach, market simulations, UC-ED, security analysis, wind power, interconnected power systems, bottleneck ranking .

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1 INTRODUCTION

Over the last decennium the long-term grid perspective for the Dutch and other European TSOs changed completely. The centralised planning of generation and transmission has been abandoned due to unbundling of these assets. In the on-going liberalisation process, the electricity markets for producers and consumers are becoming short-term and spanning over multiple countries. Moreover, the ambitious European renewable targets for 2020 and 2050 are expected to give rise to a high penetration of intermittent energy sources (wind/solar) and to a more flexible use of the conventional power plants.

For network planners these developments pose new challenges in their job of providing sufficient transmission capacity and ensuring reliability and security of supply in the long-term perspective. Nowadays, security assessment for planning purposes is limited to a number of moments in the year (planning cases) where the system is expected to be at the most stress (typically high load condition in the Dutch situation). These moments are assessed for multiple scenarios. However, the typical moment of high stress does not necessarily occur during high load conditions, as large flows in non-peak moments can also occur due to several reasons, e.g. European market integration, concentration of conventional generation far from load, large-scale offshore wind generation.

From the reasons outlined it can be concluded that it becomes more and more complex to find relevant planning cases for the assessment of grid robustness. Therefore an in-depth method has been developed to assess the robustness of the grid and give criteria for branch congestion. The method has been presented in [1]-[2] and consists of three steps:

1. market simulations
2. load flow calculations
3. determination of bottleneck ranking criteria and severity indices

The method can be used iteratively in order to find out sensitivities to various market assumptions and the impact of network reinforcements.

In this paper the first practical experiences with the round-the-year methodology applied to the Dutch grid are presented based on the methodology introduced in [2]. The presented material only covers one future scenario and two grid topologies. Detailed conclusions can therefore not be drawn for the planning of the Dutch grid, but conclusions for the computational feasibility of the method can be drawn. Also a manner of presenting the results in summarizing tables is given.

The paper is structured in three main sections and a conclusion section. In Section 2 a brief introduction of the methodology is given. Furthermore, Section 3 introduces the market and load-flow models that were used for the analysis, and Section 4 presents the results of the study case. Lastly, in Section 5, conclusions are drawn and recommendations for further work are given.

2 BRIEF OVERVIEW OF THE METHODOLOGY

The method used in this study is a round-the-year security analysis with bottleneck ranking which was introduced in [1]-[2]. The method adopts a probabilistic approach combining chronological market simulations and static security analysis to deal with uncertainties. The perimeter of the market simulations and the security analysis are not necessarily the same but the market analysis must contain at least the region that is modelled in the security analysis and preferably extend beyond.

2.1 Market simulations

The trade between the electricity generation and demand depends on many parameters which are not so easy to predict for long-term studies. The way generation and demand might interact can be modelled in market simulations. In the presented method, market simulations are performed based on a Monte Carlo probabilistic multi-area, multi-fuel, chronological simulation model for electrical power systems including combined heat and power, energy storage and energy limited fuel contracts. The tool that performs the market simulations (PowrSym4) uses a rolling Unit Commitment and Economic

Dispatch (UC-ED) optimisation, i.e. UC–ED are updated at every simulation moment based on load, wind, solar, hydro and CHP forecasts, while taking into account technical constraints following from previous states. It assumes a perfectly operating market meaning that the marginal price is set by the operating cost of the most expensive unit on-line during a given time period. The resolution of time-steps of the simulation can be chosen according to the study purposes, e.g. hourly and quarter hourly.

2.2 Security analysis

Determination of critical planning cases is a complex matter. The worst case situations for existing flow patterns can be found based on experience, but resulting worst case flows caused by new entities such as large-scale wind and solar installations are more difficult to identify. An analysis based on the outcome of market simulations can reveal planning cases that can cause the bottlenecks in the transmission system. The market simulations generate cases that are both possible and realistic. For the determination of the consequences for the network an AC, DC or combined AC-DC contingency analysis on a grid model can be performed. A trade-off between computation speed and robust solvability of DC load-flow on the one side and accuracy in voltage and reactive power for the AC load-flow on the other side is necessary.

2.3 Coupling market simulations and security analysis

Each time step of the market simulation results in a dispatch of the generation for each generation type per region and the load for each region. Next to that, commercial exchanges from each region to its interconnected neighbours are calculated in the market simulations. The market simulation results can be linked to the load-flow model as described in the following subsections.

Mapping the generation

The results of the market model provide hourly values for the generation split by categories based on fuel type, technology and age. For each generator unit in the grid model the appropriate category of the market model is selected. For every region the dispatch of the generator units for each generation category is done based on two subsequently applied principles, first by dispatch order (priority) and next by dispatch of individual generator units.

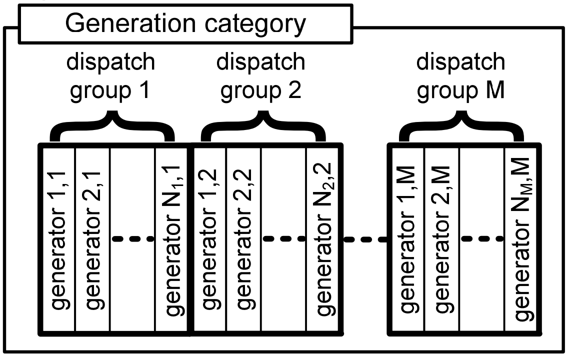

Figure 1: Generation plants of the same category arranged in dispatch groups

The dispatch group represents a list of generator units that have the same dispatch order within a given generation category. This can be seen as a merit order within the list of all generator units belonging to the same category. This concept is presented in Figure 1. The dispatch groups are ordered based on the generator units portfolios chosen for the study. The concept of dispatch groups gives the possibility to assess the consequences for the grid of multiple scenarios varying the priority to geographic location and portfolio behaviour of producers with generator units of the same category. A major advantage is that it is possible to assess these effects without rerunning the market simulations. For each dispatch group the total maximum dispatch generation is calculated as the sum of the total maximum capacity of all generators within the group ($P_{\text{cap, group m}}$). The market simulation result is split on the dispatch groups according to the specified order. Starting from the first dispatch group the generators are dispatched to their maximum capacities, until a dispatch group has been reached where the remaining power to dispatch exceeds $P_{\text{cap,group m}}$. In this case not all generators can be dispatched to their maximum capacity and two principles can be used for the dispatch of the individual generators: proportional scaling (1) and linear scaling (2).

$$P_{disp,gen,n,m} = \frac{P_{cap,gen,n,m}}{P_{cap,group,m}} P_{disp}, \quad \text{for } n = 1...N_m \tag{1}$$

$$P_{disp,gen,n,m} = \frac{P_{disp}}{N_m}, \quad \text{for } n = 1...N_m \tag{2}$$

P_{disp} is the remaining generation that needs to be dispatched in the non-fully dispatched group, $P_{cap\ gen\ n,m}$ is the capacity of the nth generation unit in the mth dispatch group and N_m is the number of generation units in the mth dispatch group.

In general embedded generation units are not explicitly modelled in the grid model, i.e. solar PV and wind turbines connected to the MV network, but they are represented in the market simulations and must thus be taken into account in the load-flow model. The total of all the dispatched embedded generation per region is summed ($P_{disp,\ gen\ embed}$) and later netted with the total load of the region.

Mapping the load

The market simulation only provides the total load per region for each modelled time-step. In the grid model this load needs to be divided among all the loads at the individual busses in the modelled region. For each load in the grid model, a part conforming to the system load pattern and a part for which the pattern is fixed, are identified. In these conforming and fixed loads there should be no contribution from embedded generation. Fixed loads can be large industries with a known constant load profile. The total fixed load in a region ($P_{ld\ fixed}$) is obtained by summing up the fixed loads at all buses. Similarly the total conforming peak load ($P_{ld\ conf}$) per region is obtained. The total conforming load that should be dispatched is:

$$P_{disp,ld\ conf} = P_{disp,ld\ total} - P_{ld\ fixed} - P_{disp\ gen\ embed} \tag{3}$$

Where $P_{disp,ld\ total}$ is the total dispatch of the regions' load in the market simulation. For each individual conforming load the dispatch of the time-step is calculated using proportional scaling:

$$P_{disp,ld\ conf,i} = \frac{P_{disp,ld\ conf}}{P_{ld\ conf}} P_{ld\ conf,i}, \quad \text{for } i = 1...N_{ld\ conf} \tag{4}$$

$N_{ld\ conf}$ is the number of conforming loads in the region and $P_{ld\ conf,i}$ is the active peak power of the ith conforming load in the region. One bus can have multiple loads attached.

Mapping the exchanges

The market simulations result in a commercial electricity exchange from each region to its neighbouring region for each simulated hour. The modelled area in the market simulations and the area covered in the grid model do not necessarily coincide. The exchanges between the regions that are included in both models should not be influencing the load-flow results as they are recalculated, more accurately, by the load-flow. The exchange to the regions outside the area of the grid model should be set explicitly for each time step. Furthermore the market model contains only one connection between each interconnected regions, where there can be multiple tie-lines between regions in the grid model. The presented approach takes into account all these issues in a pragmatic and general way. For each interconnection a set of tie-lines is defined and the dispatch is set proportional to a preset weighting value for each tie-line.

An equivalent load is placed on each of the tie-lines that are associated with the specific border to model the dispatch of the exchange. The direction of the exchange is taken into account by adapting the sign of the magnitude of the equivalent load.

If the "from-region" is in the grid model:

$$P_{disp,exch,i} = w_i P_{exch}, \quad \text{for } i = 1...N_{ties} \tag{5}$$

And if the "to-region" is in the grid model:

$$P_{disp,exch,i} = -w_i P_{exch}, \quad \text{for } i = 1...N_{ties} \tag{6}$$

where w_i is the weight of the i^{th} tie-line for the border, P_{exch} is the exchange between the from-region and the to-region and N_{ties} is the number of tie-lines on that border. A border between two regions that are both in the market simulations and the grid model will get assigned two loads with the same magnitude, but with an opposite direction. This leads to a net zero flow. For exchanges where only one of the two regions is represented in the grid model, this will lead to the desired net exchange.

Bottleneck assessment and ranking

After the mapping of the market simulation results on the grid model, a security analysis is performed. The identified bottlenecks are ranked based on a statistical risk-based analysis. Firstly bottleneck ranking criteria (see Table I) are determined for the N, N-1 and N-2 situations by using the results of the security analysis.

Table I Main bottleneck ranking criteria definitions

Criterion	N	N-1	N-2
Branch loading median for the overloaded hours	C01	C11	C21
Total number of overloaded hours of a branch	C02	C12	C22
Maximum overloading of an overloaded branch	C03	C13	C23

Furthermore, risks of overload are computed separately for each overloaded branch in the study period for the N, N-1 and N-2 situations respectively, as formulated in (7). The risk of overload of branch *i* during such situation *sit* ($RO_{sit,i}$) is given by the product between the total number of overloaded hours ($Cj2_i$) and the branch loading median for the overloaded hours ($Cj1_i$) minus the 100% overload threshold. The severity ranking index of a branch for a situation is given by its risk of overload.

$$RO_{sit,i} = \left(Cj1_i - 100\right)\cdot Cj2_i \text{ [(\%) of rated capacity}\cdot\text{hours]}, \qquad (7)$$
$$i = 1..N_B;\ j = 0,1, \text{ or } 2;\ sit = \text{N, N-1 or N-2}$$

In equation (7) j=0 corresponds to sit=N, 1 to N-1, and 2 to N-2 respectively. If N_B the total number of branches in the system analysed under a certain scenario, then the severity index for each branch can be computed as a weighted sum:

$$SI_i = w_N \overline{RO}_{N,i} + w_{N-1}\overline{RO}_{N-1,i} + w_{N-2}\overline{RO}_{N-2,i},\ \ i = 1..N_B \qquad (8)$$

SI_i is the severity index branch i; w_N, w_{N-1}, w_{N-2} are the weighting factors for the N, N-1 and N-2 situations respectively; $\overline{RO}_{N,i}, \overline{RO}_{N-1,i}, \overline{RO}_{N-2,i}$ are the normalized values of the risks of overload computed in (7). The normalization is done for each situation by dividing the each branch's risk of overload to the maximum risk encountered in that situation.

The values of the above-mentioned weights should be set according to the preferences of the decision-maker and based on the requirement for the TSO to ensure the security of electricity supply in the control area under its responsibility. Note that the choice of weights influence the ranking order of the various bottlenecks, however all detected overloads are presented.

For better assessing the relationship between bottlenecks and contingencies, two additional indices can be used for the N-1 situation as defined in [2], namely:

- C14: total number of branches that will be congested due to a given branch being not available
- C15: the total number of branches that if not available cause the congestion of a given branch

3 CHARACTERISTICS OF THE PRESENTED STUDY

3.1 *Market study*

The perimeter of the market study consists of a detailed analysis of ten countries in Northwest Europe: Belgium, Netherlands, Luxemburg, France, Germany, Denmark, Sweden, Norway, Great-Britain, and Ireland. The model was split into 14 market nodes due to grid design while neglecting the internal bottlenecks. These market nodes are connected with each other by links of limited cross-border transfer capacities. Thermal plants have been clustered into 126 different categories. Furthermore in total 54 non-thermal generation categories have been modelled. This results in a planning case for every hour in the studied year (2020). The underlying scenario is the EU 2020 scenario which has been used in reference [4].

3.2 *Grid model*

Loadings of selected branches in normal and contingency situations were determined using PSS®E version 32. DC load-flow calculations were done. The model that was used to perform the calculations for the analysis consists of a representation of the Dutch EHV grid and a small part of the HV grid where appropriate. Similarly a substantial part of the HV and EHV of the neighbouring grids of Belgium, Luxemburg, Germany and France have been included. This system is substantially meshed between the modelled countries (38 tie-lines modelled), but also between the modelled area and the rest of the interconnected system (71 tie-lines modelled). Table II gives an overview of the elements within the grid model.

Table II: Characteristics of the used grid model

Element	Busses	Machines	Loads	Branches	Transformers
Total System	4876	2582	3711	5157	1713
The Netherlands	250	80	39	122	93

The contingency analysis was performed only on the Dutch part of the grid. The surrounding countries were modelled to obtain realistic cross-border flows. Phase shifting transformers were set to their neutral position in all cases and no post-contingency generation re-dispatch is allowed. A diagram of the Dutch EHV grid is given in Appendix 1.

3.3 *Automated calculation process*

The process of exporting the hourly market simulation results into the load-flow model was automated using Python 2.5. Python is a powerful dynamic programming language under an open-source licence that can be used to interact with the load-flow tool PSS®E via an application programme interface (API). An additional advantage is that interfacing with Microsoft Excel and ASCII files is a default capability. Excel templates were used for input and output which provides both transparency in the generated cases and capabilities to visualise the results. In the analysis of the aggregated results, specific cases were easily reproducible and used for further analysis and validation.

4 RESULTS

4.1 *Computational characteristics*

In this paper N-1 and N-2 contingency analysis for a complete year are described. The analyses have been carried out on a regular computer with an Intel® Core™2 Duo P8700 processor at 2.53 GHz with 2.9 GB of RAM and a 320 GB hard disk. The computational characteristics are presented in Table III. The vast amount of produced data exists partly due to the fact that for each hour a full contingency report is stored in a plain ASCII file which can be compressed at a later stage.

Table III: Calculation reference

Type	Contingencies [#]	Monitored lines [#]	Comp. time [h]	Storage [GB]	Compressed [GB]
N-1	133	119	5	9.4	0.6
N-2	1789	119	24	154.6	5.2

4.2 Overall results

Table IV illustrates the main results of the round-the-year security analysis. All branches reported in the first column were congested at a certain moment under N, N-1 or N-2 condition. For each of them the criteria C01, C02 and C03 (for the N), C11 to C15 (for N-1) and C21, C22 and C23 (for N-2) situation were computed. Using the criteria the risks of overload were computed and ultimately the severity index for each branch using the weights 0.6 for N, 0.3 for N-1, and 0.1 for N-2 situations [2], [5]. The results of the bottleneck ranking are shown in Figure 2 and Table IV.

It can be noticed that the line between MEE and DRT (connecting the substation of Meeden to the phase shifter in Meeden) is overloaded in N, N-1, and N-2 situations and is the most frequent occurring bottleneck. The next most frequently occurring bottleneck is given by the branch EHV-MBT, followed by the lines GT-KIJ and DIM-OZN. In addition, by looking at the C15 values it can be noticed that the most frequently occurring bottleneck (between MEE and DRT) is sensitive to 125 N-1 outages (almost all N-1 outages). Also the branch DIM-OZN is sensitive to 107 outages. The same line DIM-OZN is the most critical from the perspective of C14, meaning that 9 branches are affected by the outage of this line.

Table IV: Results of the round-the-year contingency analysis

Branch	C01 [%]	C02 [h]	C03 [%]	C11 [%]	C12 [h]	C13 [%]	C14 [branches]	C15 [outages]	C21 [%]	C22 [h]	C23 [%]
EOS-EEM	0	0	0	108	57	130.1	6	1	107.1	134	134.1
DIM-OZN	102.2	1	102.2	110.35	114	130.7	9	107	110.9	645	162.6
DIM-BKL	0	0	0	105.25	88	134.3	3	1	110.7	148	139.2
EHV-MBT	0	0	0	112.2	719	148.1	6	2	118.5	1067	169.9
GT-KIJ	0	0	0	107.45	252	132.6	6	1	112.6	690	152.4
HGL-ZL	0	0	0	103.3	71	118.3	3	1	105.7	342	128.7
KIJ-BKL	0	0	0	107.7	97	129.9	5	1	109.9	181	140.5
MEE-DRT	107.1	92	139.4	122.05	1190	224.3	3	125	123.2	1652	225.3
ENS-ZL	0	0	0	0	0	0	0	0	103.9	15	111.9
BVW-OZN	0	0	0	0	0	0	0	0	104.2	43	116.1
TBG-GT	0	0	0	0	0	0	0	0	105.7	388	127
TBG-EHV	0	0	0	0	0	0	0	0	113.6	1066	152

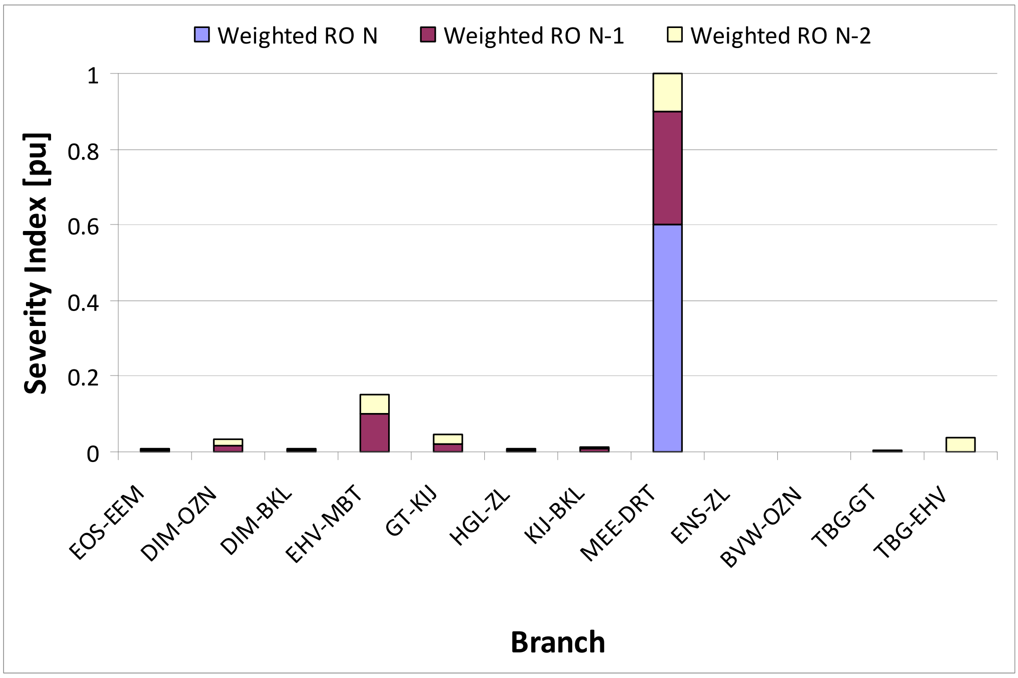

Figure 2: Bottleneck ranking for the base case, N-1 and N-2 overloaded branches in the Dutch EHV grid

For getting a better picture of the cause-effect relationships between bottlenecks and outages, the relationship between them is analysed by means of a matrix containing the number of overload instances per outage. Table V shows such a matrix for the top 5 N-1 outages (in terms of number of overload instances). On the first row the outage names are listed and on the first column the bottleneck names. At the intersection of each row and column the number of instances of branch overload due to that outage can be found. The last row sums all the number instances of branch overload per outage for the whole year.

Table V: Top 5 N-1 outages measured in instances of overload on the 380kV grid

Branch \ Outage	**MEE-DRT1[*]**	**EHV-MBT1[*]**	**GT-KIJ1[*]**	**DIM-OZN**	**KIJ-BKL**
EOS-EEM	0	0	0	0	0
DIM-OZN	1	7	3	0	109
DIM-BKL	0	0	0	88	0
EHV-MBT	0	719	0	1	0
GT-KIJ	0	0	252	0	0
HGL-ZL	0	0	0	0	0
KIJ-BKL	0	0	0	97	0
MEE-DRT	1190	82	80	79	76
Total # of overloads	**1191**	**808**	**335**	**265**	**185**

4.3 Zooming into a specific bottleneck

From the results in the previous subsection it can be seen that the severity index of the line MEE-DRT is the highest. When analysing the actual situation in the grid, this line appears to be fully controllable due to a series phase-shifting transformer in the substation of Meeden. As stated before, in the current analysis phase-shifter settings have not been optimised hence it is assumed that the setting of phase shifters would resolve this issue in most of the cases. Therefore in this paper the line with the second largest risk of overload (EHV-MBT) is zoomed into. This line is connecting the substations of Eindhoven and Maasbracht. The line EHV-MBT has been identified by TenneT in [4] as a bottleneck presenting N-1 and N-2 risks. One of the scenarios in that document is comparable to the underlying scenario for the results in this paper, namely the EU2020 scenario. The results of the N-1 assessments on a high onshore wind situation and a high offshore wind situation, both in conjunction with high load are given in Figure 3.

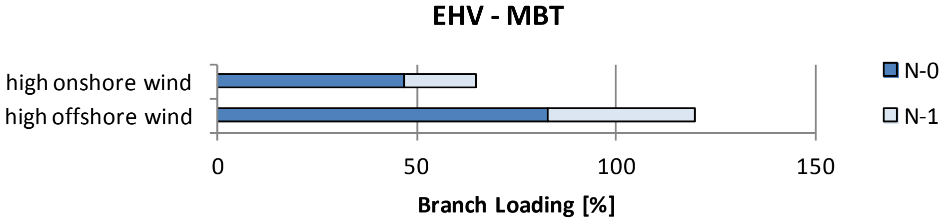

Figure 3: Results of the snapshot analysis for two high load situations [4]

One of the options for reducing this bottleneck is the increase of the nominal capacity of the line itself. The line EHV-MBT currently has a rated ampacity of 2.5 kA (1645 MVA at 380kV). The effect of increasing the rated capacity of the line to 3.0 kA (1975 MVA at 380kV) has been assessed. According to the planning case analysis, by increasing the line's ampacity to 3.0 kA, the EHV-MBT line becomes N-1 safe. However, the round-the-year analysis gives different results as shown in Table VI). It can be seen that C12, the number of overloaded hours under N-1, decreased but settled at 205 hours. The risk of overload of line EHV-MBT reduces more than ten times due to the capacity increase, but does not disappear. Hence more or other grid reinforcement measures should be probably be taken. For the other lines the risk of overload does not change and are not reported in the table.

Table VI: Effect of increasing the rated capacity of the EHV-MBT line

Case	**Capacity**	**C01**	**C02**	**C03**	**C11**	**C12**	**C13**	**RO_{N-1}**
Current capacity	2.5 kA	0	0	0	112.2	719	148.1	8771.8
Increased capacity	3.0 kA	0	0	0	104.1	205	125.2	840.5

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[*] Suffix 1 refers to the parallel circuit; for parallel circuits only one circuit is reported

5 CONCLUSIONS

In this paper a practical demonstration of the round-the-year security analysis and bottleneck ranking was made, focusing on the Dutch transmission grid for the year 2020. The use of market simulations as a basis for grid studies has been put into practice. Various scenarios for market development can be used to test the resilience of the grid for multiple possible futures, however in this paper only one scenario was used for the purpose of demonstration. The hourly results from the market simulations were used to generate representative cases for load-flow analysis. The computer resources that are needed to perform such an analysis have been discussed. With an up-to-date standard computer the presented methodology proves to be feasible with the study-time resolution of one hour for a one year evaluation of a system with 4876 busses and 5157 branches (using 133 N-1 outages and 1789 N-2 outages). The results can be compared with the traditional planning methods where only a few planning cases that represent a whole year are analysed. In a comprehensive way the presented method provides additional information with respect to the risk of overload of a transmission branch and assessing the severity of each bottleneck. Evaluation of risks helps to identify and prioritise bottlenecks in the grid. Furthermore, the method allows for emphasizing the relationships between outages and bottlenecks, revealing the most critical sensitivities in the grid. The method can be used for testing grid reinforcements in order to get insight into the effect of grid modifications aiming at reducing specific bottlenecks. The case of increasing the rated capacity of one of the main bottlenecks is checked against the bottleneck ranking criteria by using the same market simulation results. It was observed that the risk of overload was dramatically reduced but not completely eliminated for this example, while in the classical planning method the bottleneck would disappear.

This work provides the first practical results of using the round-the-year security analysis approach on a real-life case study. The used grid model is representative for the study area of the Dutch grid. More reliable results can be obtained when being able to get a better estimation of the flows on the tie-lines from the countries that are modelled in the grid model to the countries that are modelled outside the grid model. This can be achieved using Power Transfer Distribution Factors (PTDFs) established jointly by responsible TSOs i.e. by ENTSO-E.

Over the last decades the controllability of cross-border flows in the Dutch grid has been improved by installing phase shifters in many tie-lines. In the used DC load-flow model the phase shifting capabilities are not used. A more accurate modelling of the control capabilities of phase shifters should be considered.

Currently there is no feedback from the grid study results into the market simulation model. The cross border transfer capabilities are limited to fixed values per border. In a meshed system such as the north-western European grid, transit flows play an important role in allowing cross border trade. A feedback of the hourly security analysis of the grid to the market model could provide a better forecast of the flows that will occur in an integrated market with a flow-based allocation of cross-border capacity.

The method can also be used in medium-term planning for developing and assessing congestion management strategies. The flexibility that is offered in the whole process looks promising for testing various congestion management methodologies.

Last but not least, the main purpose of this paper is to show the possibilities and advantages of a round-the-year approach in TSO expansion planning, making the risks of overload assessment and severity indices part of the business decision processes.

BIBLIOGRAPHY

[1] P.G.H. Jacobs, C.P.J. Jansen, R. van Offeren, E. Pelgrum, A.R. Ciupuliga, A. Mahes and M. Gibescu, "A novel transmission system planning method combined market simulations and load flow calculations for identifying bottlenecks in systems with large RES penetration", Paper C1 202, CIGRE 2010 Paris, August 2010.

[2] A.R. Ciupuliga, M. Gibescu, E. Pelgrum, P.G.H. Jacobs, C.P.J. Jansen and W.L.Kling, "Round-the-year Security Analysis with Large-Scale Wind Power Integration", IEEE Transactions on Sustainable Energy, Volume 3, Issue 1, January 2012, Page(s):85-93.

[3] PowrSym3 operation manual: Description of the PowrSym3 computer model, OSA.

[4] Quality and Capacity Plan 2011, TenneT TSO b.v. (http://www.tennet.org/english/tennet/publications/technical_publications/quality_capacity_plan/quality_capacity_plan.aspx).

[5] A.R. Ciupuliga, M. Gibescu, "REALISEGRID D3.1.2 Report on extension and harmonisation of transmission planning criteria", November 2010, [Online]. Available: http://realisegrid.erse-web.it

APPENDIX 1: MAP OF THE DUTCH EHV GRID