SisyfosR User Guide

Prepared by: Ea Energy Analyses

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INTRODUCTION

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SisyfosR

SisyfosR is a simulation model for investigation and evaluation of power system adequacy.

The model is suitable for analyses of long-term system adequacy in bulk power systems (generation and transmission), including power system changes induced by:

- Increasing renewable penetration
- Decomissioning of thermal power plants
- Introduction of new technologies

This enables location of weak points in the power system due to insufficient transmission or production capacity.

SisyfosR performs a Monte Carlo simulation evaluating a year of operation based on a number of different runs. The runs will all investigate the same year, but with varying outage occurances on power plants and transmission lines.

Key inputs

Generation
- Capacity (MW), planned and unplanned outages (%)
- Profiles for variable generation

Grid
- Line capacities, connections and outages

Demand
- Annual consumption and demand profile

Results

Expected Energy Not Supplied (EENS) [MWh]
- Expected annual unserved energy demand (due to insufficient supply or grid capacity)

Loss of Load Probability (LoLP) [%]
- The probability of ENS occurring

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Description

A simple simulation example (illustrated to the right) with three nodes:

- **Demand** - 1000 MW (constant)
- **Generation** - Two plants of 1000MW each

The nodes are connected by lines with 2000MW capacity respectively. All lines and plants have a 10% probability of not being in service (unplanned outage). Note, that - while not the case in this example - a node can have both generation and demand at the same time.

The Loss of Load Probability can be calculated theoretically to be exactly 2.15%. SisyfosR finds the same LoLP after 1000 runs.

The statistical error can be reduced by executing a large number of runs. The number of runs required to reach a certain accuracy will however greatly depend on the complexity and reliability of the modelled system.

Network drawing
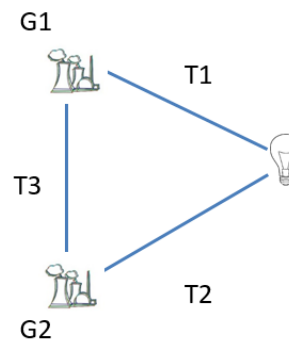
Results (1000 runs)

	ENS (MWh/yr)	LOLP (%)
Max	243.000	2,77%
75 percentage	197.000	2,25%
50 percentage	188.000	2,15%
25 percentage	163.000	1,86%
Min	140.000	1,60%

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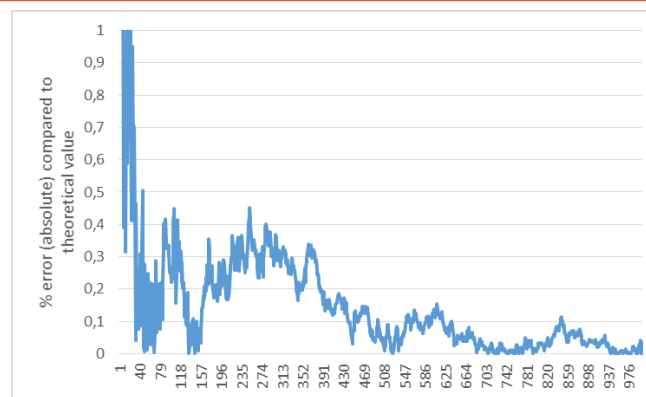
MODEL FUNCTIONALITY AND IMPLEMENTATION

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Problem formulation

System adequacy is determined by whether there is sufficient available power and grid capacity to supply the demand. The grid is taken into consideration, meaning demand can only be supplied if there is available capacity to route the supply through the grid.

This is for SisyfosR implemented by maximizing the flow of energy between nodes using the mathematical formulation illustrated below.

Terminology

The power system is defined by a set of nodes. Each node i can have a demand D_i and an available power capacity P_i. The available transmission capacity between two nodes i and j of the network is denoted C_{ij}, where F_{ij} then indicates the transmission between said nodes.
The nodes are then divided into two groups:
nodes with surplus capacity $\{i \in S | P_i - D_i \geq 0\}$
and
nodes with surplus demand $\{i \in T | D_i - P_i > 0\}$.

Energy Not Supplied can be calculated as such:

$$ENS = \sum_{i \in T}(D_i - P_i - \sum_j F_{ji})$$

Mathematical formulation
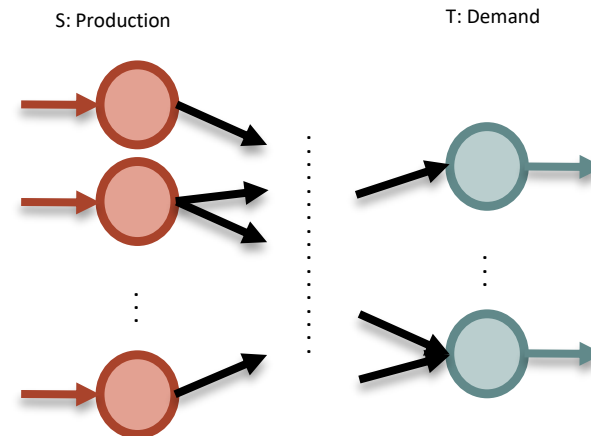
Max $\qquad \sum_{j \in T}\sum_i F_{ij}$

Where $\qquad \sum_j F_{ij} \leq P_i - D_i \,, \forall i \in S$

Outflow less than surplus capacity

$-C_{ji} \leq F_{ij} \leq C_{ij}$

Flow within capacity limits

$\sum_j F_{ji} \leq D_i - P_i \,, \forall i \in T$

Inflow less than surplus demand

Visual interpretation

S: Production   T: Demand

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Types	Technologies

The simulated hours and runs vary as result of profiles and uncertainties related to outages.

- **Demand** – Each node has an annual demand (TWh) and is assigned an hourly variation profile

- **Transmission** – For each transmission line, its capacity is multiplied with a random binomial based on its outage probability and the number of cables on the line

- **Plants** – Each plant's capacity is multiplied by a random binomial based on its unplanned outage probability and the number of its units.
  - Outage is not applied to wind or solar, as the generation profile is expected to take into account outages
  - The procedure is applied after capacity has been allocated for planned outage.

- **Node generation capacity** – Each node's available generation capacity is the sum of the available capacity of all plants located in that node

PV-panels
(*Energinet.dk*)

Electric Vehicles
(Dr.dk)

Wind turbines
(Ørsted.dk)

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Practical implementation

The model will from a user-perspective generally consist of 3 excel workbooks:

- A model file SisyfosR.xlsm, where several options (eg. number of runs, for the simulation can be set. The file contains VBA code that:

    - Prepares input data for model execution
    - Executes R-code solving the problem.
    - Reads simulation results

- A file containing all the input data describing nodes, lines & plants, and corresponding variation profiles.

- A file containing simulation results.

Number of simulation runs

A large number of runs will generally reduce the statistical error of the simulation, but will also increase the computation time. The optimal number of runs will vary on:

- The needed accuracy of the result
- The complexity of the system (more intricate systems needs more runs to portray the behaviour)
- The reliability of the system (ENS will occur less often in reliable systems, which as a result will require more runs to accurately understand)

Simulation loop

The simulation procedure is as follows:

1. Determine for each node the hourly demand based on the variation profile.
2. Load or plan outage based on the hourly demand using greedy algorithm allocation.
3. Determine the available plant capacity considering the possible variation, the planned outage and unplanned outages.
4. If calculated without the grid:
   ENS = total demand – total capacity (go to 8).
5. Otherwise, determine the available node power capacity.
6. Determine the transmission line capacity considering the possible outages.
7. Calculate a generation and transmission solution (max flow), which supplies all power demand if possible, or as much as possible.
8. If production is less than consumption, calculate the corresponding contribution to the EENS and LoLP.

MODEL INPUT

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Nodes

- **NodeName** – Identifier name of the node
- **NodeNo** – Node number (1,2,…)
- **Description** (optional)
- **NodeDemand** – Yearly node demand (TWh)
- **DemandVar** – Demand variation identifier, must correspond to a name in TVAR
- **X** – X-coordinate (used for drawing, optional)
- **Y** – Y-coordinate (used for drawing, optional)

- **RowCoo** – Row coordinates of the node (used to draw in excel, using the button DrawGrid, optional)
- **ColCoo** – column coordinates of the node (used to draw in excel, using the button DrawGrid, optional)
- **RevisionGroup** – A string linking all plants in the node to a specific planned maintenance group (optional)

Example of declaration

The nodes declared here corresponds to the example given in Slide 3.

Node name, used for identification	Increasing integer node index	Optional user description	Yearly demand including losses	Variation profile from TVAR sheet	Optional voltage declaration	GPS coordinates	GPS coordinates	Row coordinates in spreadsheet	Column coordinates in spreadsheet	Planned-maintenance group
NodeName	NodeNo	Description	NodeDemand	DemandVar	Voltage	X	Y	RowCoo	ColCoo	RevisionGroup
G1	1	Generation1	-		400			15	5	DE
G2	2	Generation2	-		400			15	11	DE
DemandNode	3	Demand	8,76	Demand1	400			15	17	

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Lines

- **LineName** – Identifier name of the line
- **FromNode** – Node name from **NodeName**
- **ToNode** – Node name from **NodeName**
- **FromNodeNo** – **NodeNo** corresponding to **FromNode**
- **ToNodeNo** – **NodeNo** corresponding to **ToNode**
- **Capacity_From2To** – Total capacity of the line in one direction

- **Capacity_To2From** – Total capacity of the line in one direction
- **Count** – Integer number of identical connections within the line
- **UnplannedOutage** – Unplanned outage probability
- **CommonFailureNo** – Index of an unplanned event that effects this line, see sheet outages

Example of declaration

The lines declared here corresponds to the example given in Slide 3.

Line name, used for identification in results	Must exist in list of Nodes	Must exist in list of Nodes	Index in list of Nodes	Index in list of Nodes	Connections total capacity	Connections total capacity	Number of lines per connection	On time basis per annum	Index, see sheet outages
					Capacity_From2To	Capacity_To2From			
LineName	FromNode	ToNode	FromNodeNo	ToNodeNo			Count	UnplannedOutage	CommonFailureNo
LineBetweenGen	G1	G2	1	2	2000	2000	1	10,0%	
G1->Demand	G1	DemandNode	1	3	2000	2000	1	10,0%	
G2->Demand	G2	DemandNode	2	3	2000	2000	1	10,0%	

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Plants

- **PlantName** –Identifier name of the plant
- **NodeName** – **NodeName** from the sheet **Nodes**, where the plant is located
- **NodeNo** – **NodeNo** corresponding to **NodeName** in the sheet **Nodes**
- **InstalledCapacity** – Total capacity installed (MW)
- **NoUnits** – Number of units in the plant
- **PlantType** – Descriptive purposes eg. Wind or nuclear (optional)
- **UnplannedOutage** – Unplanned outage probability (%)

- **PlannedOutage** – Planned outage probability (%)
- **CommonFailureNo** – Index of an unplanned event that effects this line
- **Variation** – Name of the variation profile used , must match the variation profile in the sheet **TVAR**
- **HeatDependent** – Describe how dependent the plant is of district heat demand, fx 0% for non-heat producing plants

Example of declaration

The plants declared here corresponds to the example given in Slide 3.

PlantName	NodeName	NodeNo	Installed Capacity	NoUnits	PlantType	Unplanned Outage	Planned Outage	Common FailureNo	Variation	HeatDependent
Node name, used for identification	*Corresponding to the sheet nodes*	*Corresponding to the sheet nodes*	*Total capacity*	*Integer*	*Descriptive, fx 'Wind', 'PV'*	*On time basis per annum*	*On time basis per annum*	*Index, see sheet outages*	*Variation profiles from TVAR*	*Scalar in [0,1], 0 for non-heat*
Plant1	G1	1	1000	1	CD	10,0%	0,0%			
Plant2	G2	2	1000	1	CD	10,0%	0,0%			

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Common Failures

Common failures are a way to address situations where multiple lines and/or plants would be out simultaneously as a result of an event they have in common.

- **Index** – Index of the different events

- **Name** – A descriptive name of the event that effects multiple lines and/or plants.

- **UPOutage** – The probability of the event occuring

Example of declaration

An example of a common failure is illustrated in the figure below.

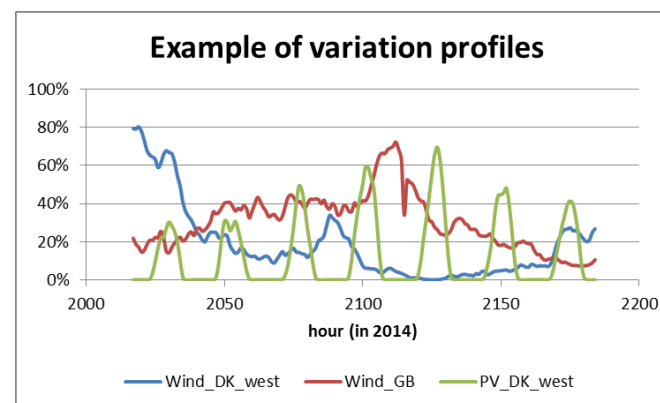| Index	Name	UPOutage
Common Failure table must be manually entered!	(Optional) descriptive name	Probability of simultaneously unplanned outage for all units with this index
1	CF1	1,00%
2	CF2	2,00%

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Variation profiles	Example of declaration

Variation profiles are given by a profile name followed by 8760 rows of values indicating the profile behaviour. The values varies slightly depending on their type.

- **Temperature** – Values must be between 0-1, and the profile name must be "Temperature". This is used to describe the heat binding for plants, where this is relevant.

- **Demand profiles** – The sum of demand in all hours must be 1.000.000 MWh (=1TWh). The profiles can be scaled with the total demand in associated **NodeDemand**.

- **Plant variations** – Values between 0-100%. Used to scale the capacity of the associated plants **InstalledCapacity**. The mean of all values equals the annual load factor, whereas the sum equals the plant full load hours.

	Demand1	Temperature	WindOffshore
Max	114,16	1,00	1,00
Average	114,16	0,54	0,52
Sum	1.000.000	4.751	4.537
Name	Demand1	Temperature	WindOffshore
1	114,16	0,45	0,72
2	114,16	0,45	0,91
3	114,16	0,45	0,84
4	114,16	0,45	0,86
5	114,16	0,45	0,88
6	114,16	0,46	0,99
7	114,16	0,45	0,98
8	114,16	0,44	0,99
9	114,16	0,44	0,99
10	114,16	0,46	0,98
11	114,16	0,46	0,95

Example of variation profiles

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RUNNING THE MODEL

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Setup

The *Scenarios* sheet of the Sisyfos datafile is optimal for configuring the settings for your scenarios. The *AllScenarios*-range holds all the names of your scenarios. The various settings related to the simulations can be placed beside this and be extracted where needed in the workbook with the excel function VLOOKUP.

AllScenarios-range

Scenarios:	Scenario_setup	Scenario settings	
	Currently_running	ScenarioName	Year
Scenario1_2020			
	Scenario1_2020	Scenario1	2020
	Scenario1_2025	Scenario1	2025
	Scenario1_2030	Scenario1	2030
	Scenario2_2020	Scenario2	2020
	Scenario2_2025	Scenario2	2025
	Scenario2_2030	Scenario2	2030

A specific scenario can then be accessed using the dropdown-menu in the scenarios range.

Scenarios-range

Scenarios:	Scenario_setup	Scenario settings	
	Currently_running	ScenarioName	Year
Scenario1_2020			
	Scenario1_2020	Scenario1	2020
	Scenario1_2025	Scenario1	2025
	Scenario1_2030	Scenario1	2030
	Scenario2_2020	Scenario2	2020
	Scenario2_2025	Scenario2	2025
	Scenario2_2030	Scenario2	2030

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Description	Extract from SisyfosR.xlsm

Description

1. Input the full data-file name
2. Input the name of the desired scenario. All scenarios in the *AllScenarios*-range will be run, if left blank.
3. Set options
   a) R-path
   b) Desired number of Monte Carlo runs.
   c) Line data is disregarded, if set to *False/Falsk.*
   d) Added to demand in each hour distributed to nodes based on their level.
   e) ENS smaller than this level is considered irrelevant. Plants smaller than this are omitted.
   f) Possibility of loading pre-generated outage plan.
   g) Summary data about ENS as a yearly duration curve will be printed in the Results-sheet, if set to *True/Sand.*
   h) The simulation will be the same each time the model is run given the same input and options, if set to *True/Sand.*
   i) Unplanned plant outages will be based on average outage durations, if set to *True/Sand (include "AvgHoursOut"-column in plants)*
   j) Generates the data folder *Data_myScenarioName* based on the scenario name.
   k) Run the SisyfosR- model and generates the results folder *Results_myScenarioName* based on the corresponding data folder.
   l) Load results based on scenario name into the *Results.xlsx* file and sheet named after the scenario name.
4. Execute model based on decisions made in 3.

Extract from SisyfosR.xlsm

1.	Select data file	SisyfosRTestdata_2nodes.xlsx
2.	Select senario	
3.	Set options	a) C:\Program Files\R\R-3.5.0\bin\Rscript.exe

b	Number of runs	2
c	With grid	TRUE
d	Buffer	0
e	Tolerance	1
f	Load outage plan	dummy
g	ENS Duration curve	TRUE
h	Fixed randomness	TRUE
i	Semi-real-time outa	FALSE
j	Generate data	FALSE
k	Run model	FALSE
l	Load results	TRUE

4.	Run the model	**Run Simulation**
5.	Progress status	Done.
	Calculation time	00:03:30
6.	View results	

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RESULTS

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Loading results

Loading the results can be done from the *SisyfosR.xlsm* file.

Doing this will create a file called new *Results.xlsx*, which will then hold the results of the chosen scenario(s).

If a *results.xlsx* have been created previously and the new results are desired to override/be added to the previous workbook, then make sure to have this file open during the load.

Results overview

The first part of the scenario results sheet can be seen below. This shows first of all the input options, which was used when running the scenario.

The overall system results can be found in the results overview. Here you will be able to find the EENS, expected missing generation capacity, LoLP (%) and the probability of missing generation capacity.

The above results can be found as the average, the quantiles and for the extremes.

Example of results

The results shown here corresponds to the example given in Slide 3.

Input Options			Result Overview		ENS (MWh/y)	Missing cap (MWh/y)	LOLP (%)	Missing cap (%)
Option	Value							
Number of runs	1.000		Total avg		188.102	87.482	2,15%	1,00%
With grid	SAND		Max		246.000	126.000	2,81%	1,44%
Buffer	0		75 percentage		197.000	94.000	2,25%	1,07%
Tolerance	1		50 percentage		188.000	87.000	2,15%	0,99%
Load outage plan	FALSK		25 percentage		161.000	69.975	1,84%	0,80%
ENS Duration curve	SAND		Min		143.000	56.000	1,63%	0,64%
Fixed randomness	SAND							
Semi-real-time outage	FALSK							
Generate data	SAND							
Run model	FALSK							
Load results	FALSK							
Model Run time (s)	516							
Model Run date time	13-12-18 15:18							

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Node results and asset availability

The result of outages in the specific nodes can be seen in the Node Results section.
The EENS, missing generation capacity and LoLP can here be found disaggregated per node.

In the example presented below it can be seen that all three indicators for nodes *G1* and *G2* are zero. This is a result of them not having zero demand.
Node *DemandNode* do however values (above zero) for all three indicators. These are in the case of a singular demand node identical to the overall system indicators.

Missing generation capacity will in multi-noded systems be split across all nodes with ENS weighted by their corresponding ENS.

The plant and line availability can be found in their respective section of the *results.xslx.* In these sections can the capacities and availability be found. The availability for lines and plants without profiles indicates the percentage of hours in which the asset is available.
The availability for plants with profiles is given as the annual load factor.

In the example presented below it can be seen that all capacities are as presented in Slide 3.
Availabilities for all assets are very close to 90%, which corresponds well to the 10% outage probability.

Example of results

The results shown here corresponds to the example given in Slide 3.

Node Results	ENS (MWh/y)	Missing cap (MWh/y)	LOLP (%)	Plant Availability	Capacity (MW)	Availability (%)	Line Availability	Capacity -> (MW)	Capacity <- (MW)	Availability (%)
G1	0	0	0,00%	Plant1	1.000	90,00%	LineBetweenGen	2.000	2.000	90,01%
G2	0	0	0,00%	Plant2	1.000	89,99%	G1->Demand	2.000	2.000	89,99%
DemandNode	188.102	87.482	2,15%	Total average	1.800	89,99%	G2->Demand	2.000	2.000	90,01%

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Event log

The first 10.000 individual ENS events can be found in the section called *Event log of ENS*.
This shows the number of plants and lines which are out for the specific hour. The amount of ENS and/or missing generation capacity can also be found here. The total available capacity, capacity from plants with profiles and unavailable capacity are also present here.

This can be used to get an overall idea as to what had happened in the hour in which the ENS occurred.

It can be seen in the example below that an ENS event occurred in hour 43 of the first run. From the event log it can be seen that no plants were out in the hour, but that two lines however were. It can from this be inferred, that the two lines connecting the generation nodes and the demand node were out, which would thereby result in ENS.

A similar event can be found in hour 293 of the first run. It can be seen from the event log, that both plants were out in the hour, which none to supply the electricity demand, thereby causing ENS.

Example of results

The results shown here corresponds to the example given in .

			Total no	Total no						
			3	2						
Event log of ENS										
Run	**Hour**	**No. lines out**	**No. plants out**	**ENS (MW)**	**Missing cap (MW)**	**Demand (MW)**	**Capacity (MW)**	**Sun+Wind (MW)**	**Capacity out (MW)**
1	43	2	0	1.000	0	1.000	2.000	0	0
1	58	2	1	1.000	0	1.000	1.000	0	1.000
1	147	2	0	1.000	0	1.000	2.000	0	0
1	164	2	0	1.000	0	1.000	2.000	0	0
1	240	2	0	1.000	0	1.000	2.000	0	0
1	293	0	2	1.000	1.000	1.000	0	0	2.000
1	300	3	1	1.000	0	1.000	1.000	0	1.000

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Histogram data – Capacity surplus

The histogram data of capacity surplus section of the results investigates the number and sizes of occurrences, hours of missing generation capacity and ENS in relation to the hour capacity surplus.

All hours above 100% and below -100% capacity surplus have been rounded to these boundaries.

An example of the histogram data of capacity surplus can be seen below. The raw data can be seen on the left, and plotted on the right. The plot shows the number of hours with ENS and missing generation capacity. It is clear from the plot that the ENS will also happen for hours with positive capacity surplus. This as a result of outages, lacking connections or capacity in the transmission grid.

Example of results

The example of results shown here is not from the example used until now, but rather from runs of a more advanced grid. The model has been simulated using 5000 runs.

Histogramdata of Capacitysurplus

	Capacity surplus (%)	Occurrence (#)	Missing cap (#)	ENS (#)	Missing cap (MW)	ENS (MW)
93	-7,00%	0	0	0	0	0
94	-6,00%	8	8	8	190.624	214.504
95	-5,00%	300	300	300	6.081.106	7.097.467
96	-4,00%	3.023	3.023	3.023	49.402.860	59.800.841
97	-3,00%	9.456	9.456	9.456	116.733.437	144.424.810
98	-2,00%	13.589	13.589	13.589	111.277.047	155.482.955
99	-1,00%	16.519	16.519	16.519	67.182.937	141.524.093
100	0,00%	15.480	7.993	14.407	8.346.838	70.412.440
101	1,00%	15.023	0	7.036	0	12.136.802
102	2,00%	17.337	0	6.424	0	11.500.901
103	3,00%	28.486	0	9.243	0	19.152.757
104	4,00%	35.482	0	8.950	0	13.964.697

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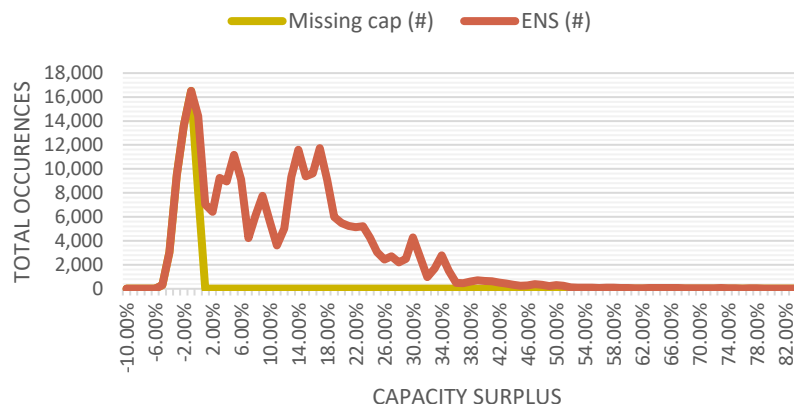
Histogram data – Capacity surplus - node

The average number of hours at a given capacity can be seen in the histogram data of capacity surplus per node section. This can be used to identify the role of a specific node in the simulated system.

It can be seen from results illustrated in the histogram below that DK East tend to have capacity surplus, but wont have an excessive surplus. The node will thereby often be an exporter of energy.
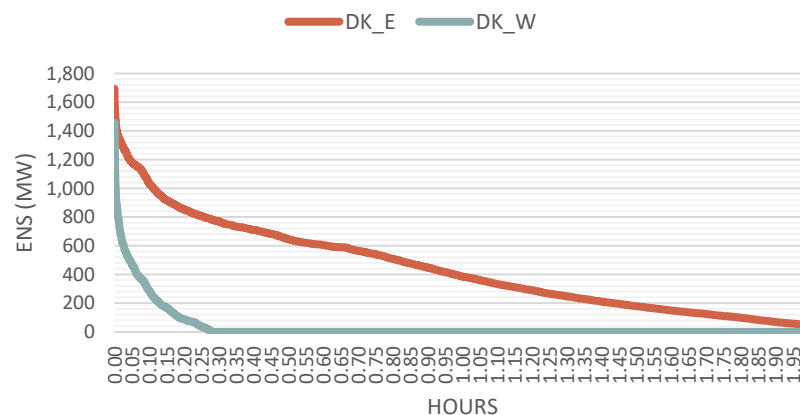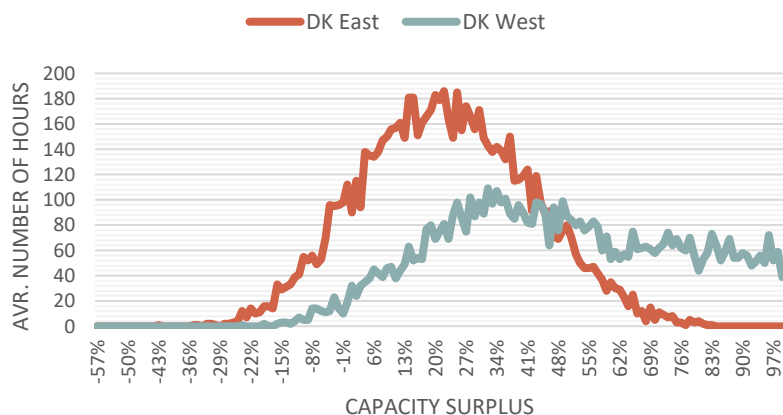
From the same graph it can be seen that DK West will have a capacity surplus in almost all hours. The node can thereby be seen as an exporter of energy in the simulated scenario.

The average length of nodal ENS can be interpreted based on the data in all ENS events per node. This lists the 10.000 largest events of ENS sorted by size. Each of these represents an hour of outage in the overall simulation. The 1-hour duration of the outage can thereby be divided by the total number of simulated hours to represent the relative influence of the event.

It can be seen from the graph below, that DK East should expect to have one hour of ENS events above 400MW in the simulated year. The results in this graph could be used for evaluating needed reserve power in a specific simulated region.

Example of results

The example of results shown here are from a model of Northern Europe. The model has been simulated using 5000 runs.

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