Semi annual ETSAP WORKSHOP

Electricity grid expansion analysis using TIMES and NEPLAN

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Background

Work done in the framework of Service Contract 109230 "The integration of TIMES-based energy system modelling with electricity grid modelling"

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to

- **C**entre for **R**enewable **E**nergy **S**ources & Saving (CRES)
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- Subcontracting:
  KANORS-EMR
  VTT Teknologiasta liiketoimintaa

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Background

A TIMES model does not consider in detail the analysis of a power system. It includes a rather elementary approach for dispatching, transmission and non dispatchable RES generation.

The combined problem of optimum power systems generation and transmission expansion is a rather challenging complex task.

The target of the project is to achieve an effective cooperation of energy system models performing long-term planning with power system modelling, so that results coming from both aspects are compatible and mutually connected.

A load flow analysis can be performed in order to examine the adequacy of system transfer capability, verify voltage level system substations and finally determine any network reinforcement needed (transmission lines, capacitor banks etc.) for several system loading conditions.

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Load flow problem

- Snapshots (e.g. hourly, max load, min load etc.) of the operating conditions of a power system
- Starting point of power system study
  - Determines operation equilibrium
- Provides overall monitoring of line loading and voltage levels
  - Calculation of **the *power flows* across the *circuits* of a power system**
- Basis for Security Analysis
- Provides insight for future expansion of the network
- Required Data:
  - Generator P and V, Loads P and Q

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Load flow problem

- AC formulation –> Non Linear Problem

- DC formulation
  - Simplified solution
  - Linear problem
    - Voltage angle differences very small: $\sin(\Delta\delta) \approx \Delta\delta$, $\cos(\Delta\delta) \approx 1$
    - Line resistance too small: R<<X
    - All voltages == Rated values
  - Provides line flows only

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Static Security Assessment

- Normal operating conditions ("N" criterion) → all system elements in service
  - Voltage levels ± 5% of the nominal value
  - Line loading < 100% of capacity

- Emergency operating conditions ("N-1" criterion) → loss of any key component (line, generator, etc.) one at a time
  - Voltage levels ± 10% of the nominal value
  - Line loading < 100% of capacity

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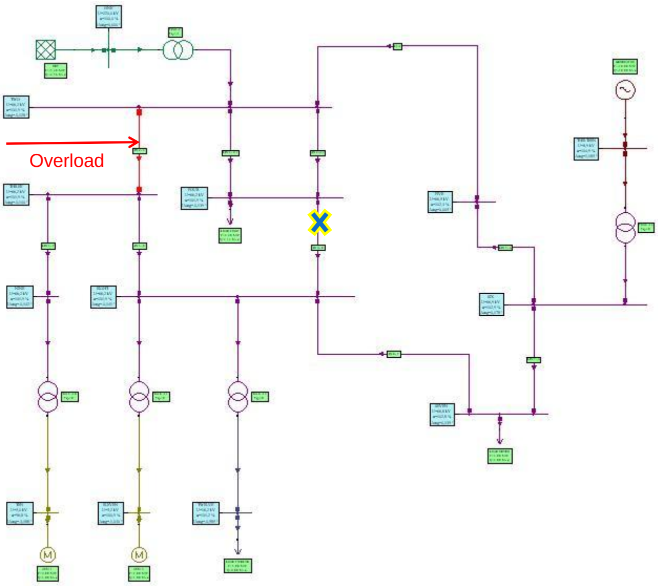
NEPLAN Contingency Analysis



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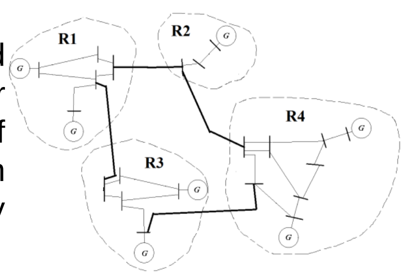
DC-Load flow in TIMES

Defining the Grid

- All grid transmission lines are bi-directional trade processes
- Grid nodes are represented in TIMES by specific electricity commodities;
- The generation and demand of electricity can be either explicitly modeled for each of the grid nodes, or they can also be automatically allocated to the nodes;



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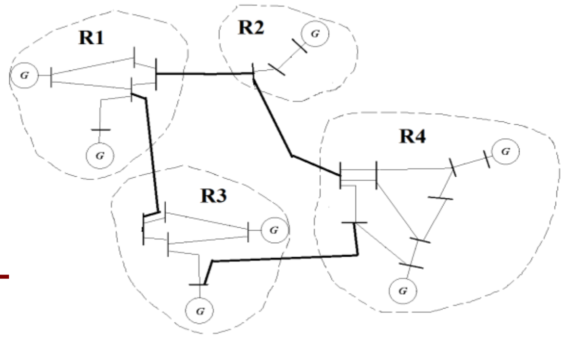
Linear DC Power Flow Equations

- The **reactances** (inverse of susceptance) for the transmission lines are defined by PRC_REACT(r,y,p).
- For inter-regional lines, the parameter can be defined on either side of the link (if defined on both sides, the maximum value is taken);



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Allocating Generation and Demands to Nodes

- The regional demand for electricity can be allocated to the grid nodes in two alternatives:
  - A. By allocating the total demand in each time-slice to the grid nodes; or
  - B. By allocating each sectoral electricity demand to the grid nodes.

- Approach A: total demand in each timeslice ts is to be allocated to each grid node ***N***, parameter:

GR_DEMFR(reg, y, N, ts): the fraction of the demand in timeslice ***ts*** to be allocated to the node ***N*** in region ***reg***;

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Allocating Generation and Demands to Nodes

Approach B, the demand for each sectoral electricity ***elcs*** is to be allocated to each grid node ***N***:

- Parameter GR_ENDFR(reg, y, N, elcs) specifying the fraction of the sectoral demand for ***elcs*** to be allocated to the node ***N*** in region ***reg***;
- As the demands usually represent amounts after endogenous transmission losses, one can additionally specify approximate transmission losses for each sectoral demand ***elcs*** by using the GR_ENDFR(reg, y, elcs, elcs) parameter, representing the amount of losses in proportion to the demand; otherwise all transmission losses are allocated to an (arbitrary) single node;

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Methodological Approach for coupling the two models

The same electricity grid is used into both TIMES and NEPLAN.

Steps Involved:

- DC power flow is solved in TIMES using for each line an availability equal to ε_{ij} (coefficient that represents into TIMES the restriction of the use of a line i-j in order to avoid overloading under N-1 security analysis). TIMES calculates necessary new line investments.
- The results of TIMES (calculated loads, electricity production, installed capacities, new line investments etc. are used as input into NEPLAN).
- Based on this input NEPLAN performs an N-1 security analysis to re-define the ε_{ij} coefficient for each line of the transmission grid. This goes back into TIMES.
- Convergence is achieved when there is no new line investments in TIMES.

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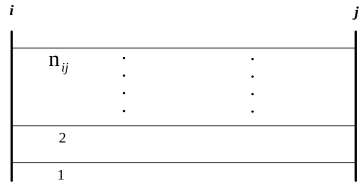
Initial ε_{ij}

- If $n_{ij}>1$, the initial value of εj is computed as follows:



$$\varepsilon_{ij} = \begin{cases} \dfrac{\min\left\{\sum_{n_{ij}-1} \mathrm{P}_k^{max}\right\}}{\sum_{n_{ij}} \mathrm{P}_k^{max}} & \text{, if } n_{ij} > 1 \\ 0.9 & \text{, if } n_{ij} = 1 \end{cases}$$

P_k^{max} is the capacity of the k_{th} circuit of the i-j connection.

$\min\left\{\sum_{n_{ij}-1} \mathrm{P}_k^{max}\right\}$ is the minimum of ΣP_k^{max} each time removing one of the n_{ij} circuits of the i-j connection.

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NEPLAN: N-1 Security Analysis

Given an electrical network consisting of *N* lines:

1. Set one line out of order and perform a load flow analysis (*N*-1 state).
2. Compute the power flows in all lines. Observe which lines are overloaded and store the power flows of the overloaded lines.
3. Re-calculate the value of εij which will ensure N-1 security: When the network is insecure, let us suppose that the line i-j is overloaded by ΔP when the line k-m is lost. Then, the correction of into NEPLAN is computed as follows:

$$\Delta\varepsilon_{ij} = \frac{\Delta \mathrm{P}}{\mathrm{P}_{ij}^{max}}$$

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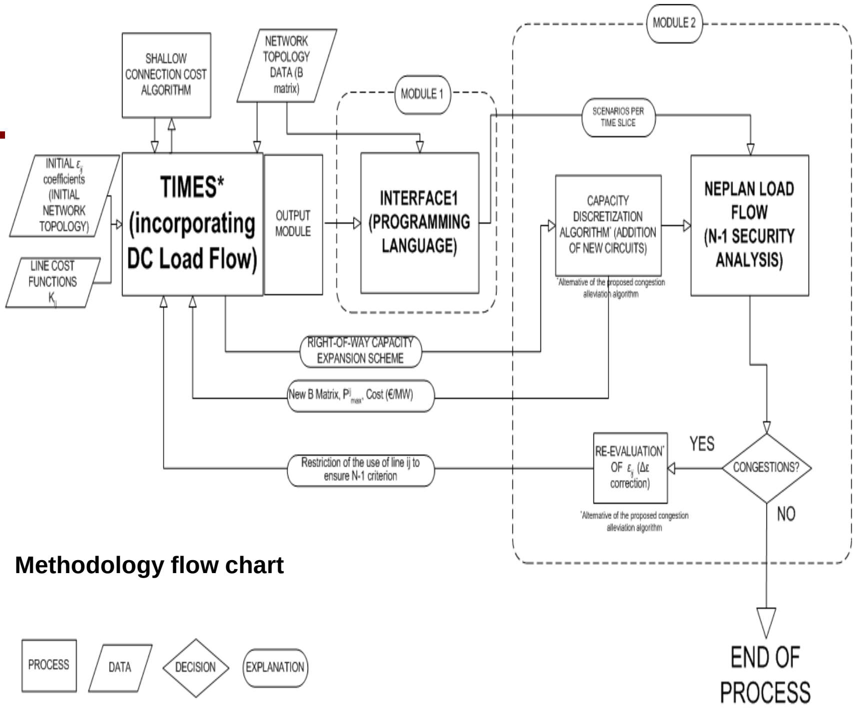

Methodology flow chart

Initial Results: Testing two approaches

Approach 1

1.Run TIMES without MIP

2. Discretise the investments externally, calculate new reactances and new ε per line per time period.

3.Run TIMES again using the data from 2 (new investments -> Lower bounds for given lines only)

4.Give the results to NEPLAN

Approach 2

1. Run TIMES with MIP

2. Give the results to NEPLAN

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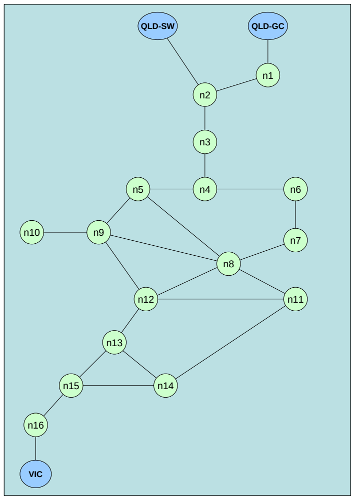
Testing two approaches

Simplified single region model to test the procedure

References:

- Modelling Liberalised Power Markets, A.D.J. Stiel, MSc Thesis ETH, 2011
- Grid and Power Flow Modeling in TIMES on VEDA-Forum by Antti Lehtila



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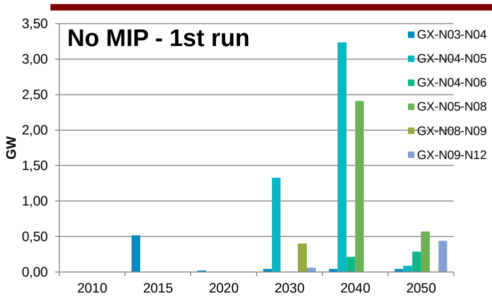
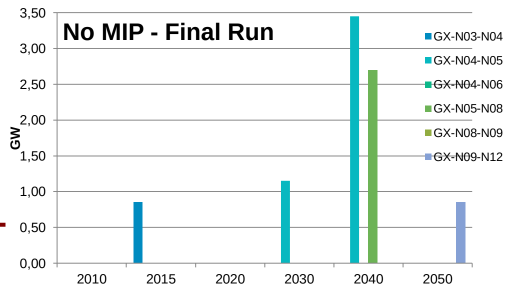
Results – New line investments





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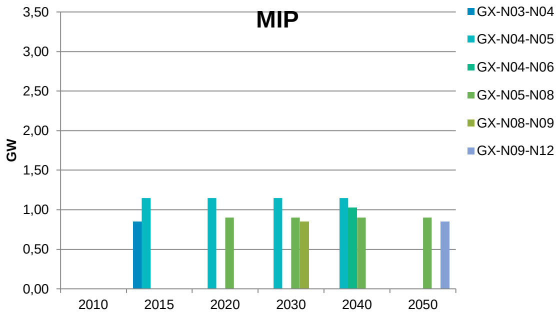
Results – New line investments



Total New line investments

No MIP case: 9GW
MIP case: 11.7GW

No-MIP Final (no new investment if the requirement is < 50% of existing line cap.)

New Investments (GW)	2015	2020	2030	2040	2050	Total New Inv.
GX-N03-N04	0.85					0.85
GX-N04-N05			1.15	3.45		4.6
GX-N04-N06						
GX-N05-N08				2.7		2.7
GX-N08-N09						
GX-N09-N12					0.85	0.85
						9.00

MIP Solution

New Investments (GW)	2015	2020	2030	2040	2050	Total New Inv.
GX-N03-N04	0.85					0.85
GX-N04-N05	1.15	1.15	1.15	1.15		4.6
GX-N04-N06				1.025		1.025
GX-N05-N08		0.9	0.9	0.9	0.9	3.6
GX-N08-N09			0.85			0.85
GX-N09-N12					0.85	0.85
						11.77

Conclusions – Next Steps

- DC-load flow incorporated into TIMES: more realistic generation patterns, electricity flows investment costs.
- Iteration with NEPLAN: incorporate N-1 security assessment.

Next Steps:

- Implementation of the method in a multi-regional Greek TIMES model (14 regions and ~100 grid nodes for the electricity network).
- Application of the methodology in PET using a very simplified electricity grid topology.

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