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1. Introduction

Over the past years VTT has developed a platform that combines different energy system models under the same user interface and database. The platform is called Sceleton. The purpose of the platform is to enable accurate modelling of future energy systems with large amounts of variable generation mainly from wind power and PV. A single model cannot achieve this, since variable generation will impact several very different time resolutions. These require specific models.

The platform currently connects three models: Balmorel, WILMAR and PSS/E (**Figure 1**). Balmorel is used for generation planning. It takes variability into account by forcing chronological constraints related to e.g. hydro power reservoirs. WILMAR is a unit commitment and dispatch model, which can take stochastic inputs for wind power, PV, and load forecasts. It has a 36 hour horizon and typically rolls through the whole year. PSS/E is a power system simulator, which can be used for static or dynamic power system stability studies. The operation of the models can be interlinked. Balmorel sends investment decisions to WILMAR, which then analyses operational costs in more detail. WILMAR in turn sends nodal electricity demand as well as unit dispatch to PSS/E, which can then be used for analysing the power flows and the stability during and after disturbances. Relevant constraints can then be fed back to the upper level model for iteration.

Sceleton uses a single database to hold input data to all models. This ensures consistency between model inputs and reduces overhead on database maintenance, since there are overlapping inputs. The results of different models can be plotted directly from Sceleton or exported to clipboard for use in other programs like Excel or Matlab. Sceleton contains scenario and case configuration selection and can be set to run multiple different model runs in conjunction. It automatically maintains result folders for different model runs.

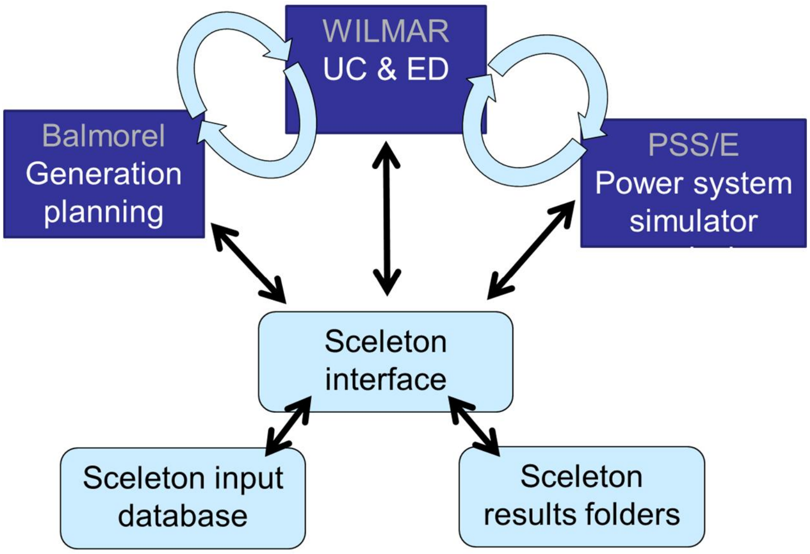

Figure 1. Diagram of the modelling platform.

This report briefly describes the different models and then outlies the basic functionalities of Sceleton. Sceleton is made to be modular in order to incorporate new models. Hence, the report describes the Scelton API. Energy system models tend to have model specific configuration, input and output formats and therefore there will always be some work to incorporate new models in the framework. In addition, any interactions between different models need to be coded.

2. Balmorel

Balmorel is a generation planning model that optimizes investments in power and heat generation as well as in transmission interconnections. It considers temporal chronology and can therefore make reasonable investments also when considering high shares of variable generation.

Balmorel is a model developed by Hans Ravn of RAM-lose edb. It is written in GAMS (General Algebraic Modeling System) language. While GAMS needs a license, Balmorel itself is open source and available at www.balmorel.com. Balmorel is a regional model where each country can be divided into several zones representing different price zones or regions. The regions can be further divided into areas representing different district heating grids. Several years can be simulated consequently. One year is divided into seasons (typically weeks) and a season is divided into time segments (typically hours). It is possible to use either all or only some of the seasons and time segments in the simulation.

The model minimizes the total investment and operational costs of the system taking into account:

- The balance of supply and demand of electricity and heat
- Reserve power demand
- Possible investments in new generation and transmission capacity
- Power plant and transmission line capacity restrictions, efficiencies
- CHP generation is within limits
- Hydro reservoirs and other storages are within limits

The model input includes:

- Sets for geographical regions, time segments, generation technologies, fuels and flexible demands
- Parameters for power and heat demand, wind power variation, solar power variation, water inflow and hydro reservoir characteristics, reserve power demand, power exchange with third countries, generation technology data, fuel characteristics and prices, flexible demand quantities and prices, transmission capacities and losses, and taxes

There are only few modifications made to the Balmorel. The main thing is to replace the input files with code that reads input from the Sceleton database.

3. WILMAR JMM

WILMAR Joint Market Model (JMM) optimizes the unit commitment and economic dispatch of power plants in the time scale of 36 hours. It can be used to plan how power systems should be operated when there is high share of variable and uncertain power generation. It is one of the first models capable of stochastic unit commitment decisions – i.e. it can take several forecasts and optimize in regards to their uncertainty.

WILMAR JMM was first developed in an EU project WILMAR (2002–2004), where VTT was one of the participants. It bears resemblance to Balmorel and is also written in GAMS. The original version of JMM is available at http://www.wilmar.risoe.dk/. Since then several institutes have developed JMM further and consequently there exists several different advanced versions of JMM.

WILMAR JMM is a zonal model where each country can be divided into several zones representing different power price zones or regions. The regions can be further divided into areas representing different district heating grids. JMM is an hourly model, where the day-ahead market is cleared at noon each day. Subsequently intra-day market is cleared every three hours as new forecasts arrive.

WILMAR JMM minimizes total operational costs of the power system while constrained to maintain balance between generation and demand of electricity and heat, respect reserve requirements, meet balancing needs that arise due to forecast errors, respect power plant efficiencies, ramping constraints and start-up characteristics, transmission limits between regions as well as dynamic equations related to hydro reservoirs and other storages.

WILMAR JMM takes similar input data as Balmorel:

- Time series of Wind power production and power demand (predicted and realized values), also stochastic tree
- Time series of solar power production, heat demand, water inflow (or water values), reserve power demand, power exchange with third countries (realized values)
- Generation technology data (capacity restrictions, efficiencies, lead times, costs, etc.), fuel characteristics and prices, flexible demand quantities and prices, transmission capacities and losses, emission and other taxes

Compared to the original version, VTT's version of JMM includes also stochastic load, outage scheduler, module for plug-in electric vehicles, unit start-ups, piecewise linear power plant efficiency also for aggregated units, water value model, more refined frequency reserve structure, variable generation in all reserves, possibility for 60-hour horizon, and MATLAB-based primary frequency response model.

4. PSS®E

PSS®E (Power System Simulator for Engineering) is a set of programs by SIEMENS PTI that can be used for analyzing and simulating power transmission systems. PSS®E has capability for power flow and short circuit analysis, equivalent network construction and dynamic simulations. PSS®E needs a license.

Power flow calculation is performed for steady-state situations. Power flow calculation refers to the following procedure: given the electrical parameters of the grid components, the switching state of the grid, the power demand in each grid node and the power production in each grid node, calculate the voltage in each node and the power flow on each branch. In its complete version, power flow problem is non-linear and requires iterative solution methods.

The input that PSS®E requires for power flow calculation is a steady-state grid model. The grid model should include the topology of the grid and basic data about the lines, transformers and other grid components, including the electrical parameters and the status of the component. In addition, grid loads and generator outputs as well as grid voltage controls should be defined in the grid model. Grid model constructed at VTT is visible in Figure 2.

Power flow calculation can be used, e.g., to determine whether a certain unit dispatch and electricity demand situation would lead to overloading of transmission lines or unsuitably high or low voltages.

Dynamic simulation refers to analyzing the behavior of the power system in time domain. Dynamic simulation begins with determining the initial steady-state situation by the means of power flow calculation. After the initial state is determined, a disturbance (e.g., disconnection of a line) or other change (e.g., a change in load levels) is simulated and PSS®E calculates how voltages, power injections and power flows change in time. The simulation may end in a new steady-state situation or a power system collapse, depending on how severe the disturbance is for the initial state. The time frame for the dynamic phenomena that can be simulated using PSS®E ranges from approximately tens of milliseconds to tens of seconds. In dynamic simulations more data is required than in power flow calculation, especially on turbine generators and their components.

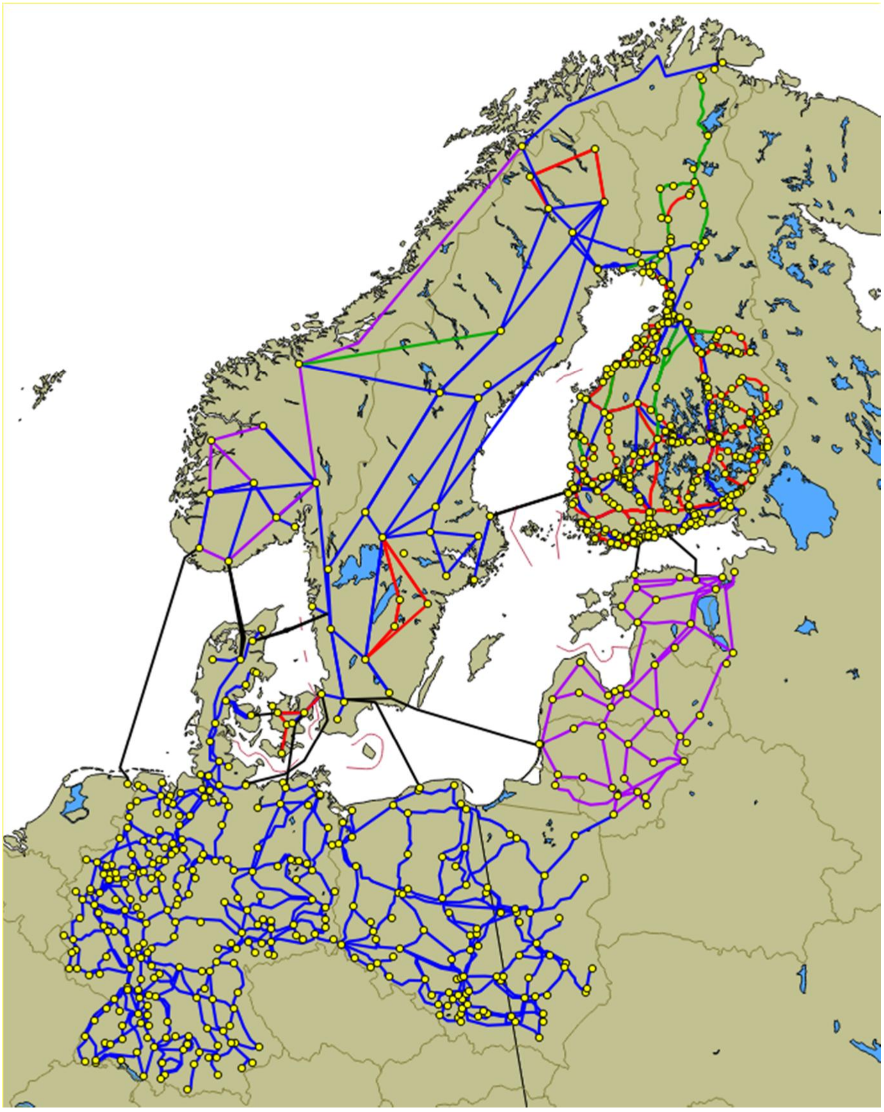

Figure 2. Baltic Sea region grid model.

5. Sceleton GUI and API

Sceleton has been developed to connect power system models operating at different time scales (currently Balmorel, WILMAR and PSS/E). It is also made to facilitate the process of running multiple scenarios and to create graphics from the results of these scenarios.

5.1 Scenarios and configurations

Sceleton has a two level structure for making different simulation runs. Scenarios contain variations in the input data and configuration chooses the settings under which the model is run. The interface is used to select the combination of scenarios and configurations to be simulated. Scenarios are defined in the database and can be modified along with the actual data using any database interfacing application. Configuration file is read and modified by the Sceleton interface. Sceleton also stores different configurations for later use. Depending on what combination of scenarios and configurations are selected, Sceleton copies input data to the model and modifies the model configuration file before starting each scenario/configuration run.

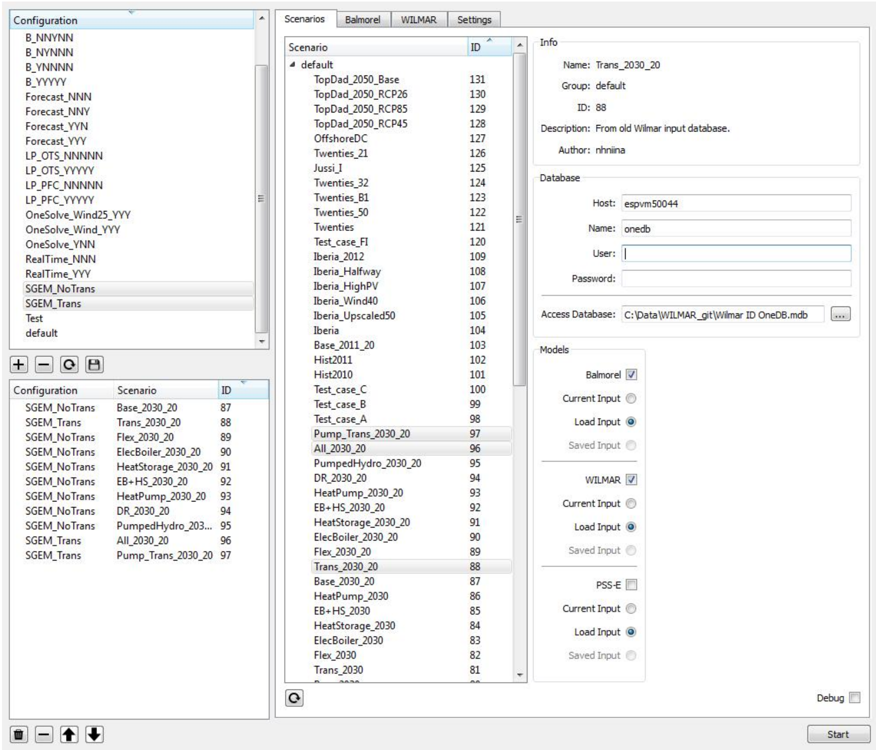

Figure 3. Sceleton interface for selecting scenarios, configurations and models to be used in the next runs.

5.2 Model data

Data for all the model tools are kept in a single centralized database. The database is backed up daily. Model input data is created using database queries – one query for each parameter. Queries are written in SQL language and stored as text files bearing the model parameter name. Sceleton runs the stored queries and stores results in a format that is readable by the model tool.

While both Balmorel and WILMAR JMM currently use a collection of text files (comma separated files, csv) for data input, Balmorel uses more efficient *GAMS data exchange* (GDX) files as its output format. GDX is a platform independent binary data format, and uses less disk space for same amount of data than a corresponding text file. Future development includes moving completely into GDX format, which speeds up model runs and simplifies the handling of multiple model cases (only one file per model case for input and output).

5.3 Outputting Results

Sceleton's Results window allows the plotting and copying of the simulation results for Balmorel and WILMAR JMM. It is relatively straightforward to add new plotting options based on the data outputted by the models. However, results for Balmorel are read directly from the outputted *GDX* file while for WILMAR the data is read from csv text files. Once JMM has been developed further, it should also output a GDX file, reducing the complexity of Sceleton and increasing its flexibility.

There is a feature to copy all of the plotted data to the clipboard in a csv format, making it easy for more detailed analysis in e.g. MS Excel.

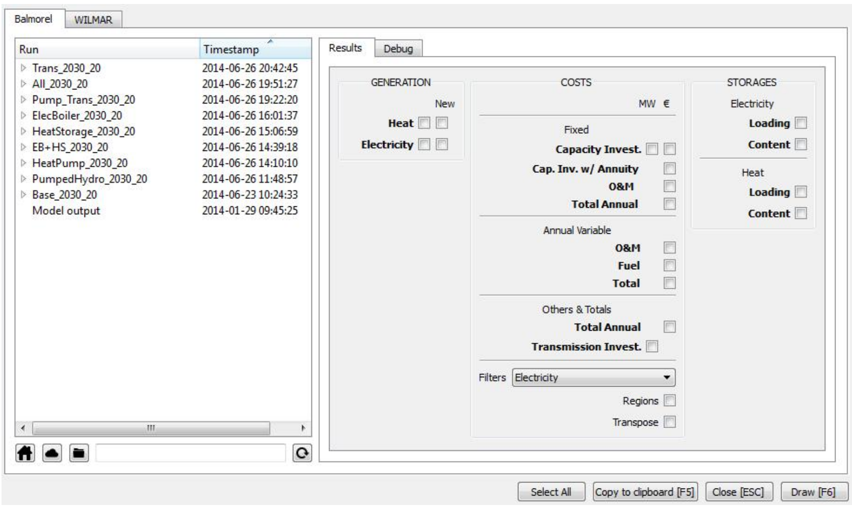

Figure 4. Sceleton's results window for Balmorel simulations.

Currently there are three main types of results being analyzed:

- **Generation:** a time series of the heat/electricity generation of the new/old units. They are line plots
- **Costs:** various costs such as capacity investments, operational, fixed O&M costs, etc. These can be separated by regions and/or have either the unit type or the regions in the bottom axis. They are clustered stacked bar plots.
- **Storages:** a time series with either the loading or the content of the various electricity and heat storages. They are line plots.

Sceleton has been developed in a way that multiple scenarios and configurations are allowed to be compared with each other. It is also possible to split/aggregate the data in regions per user command. Some examples can be seen below:

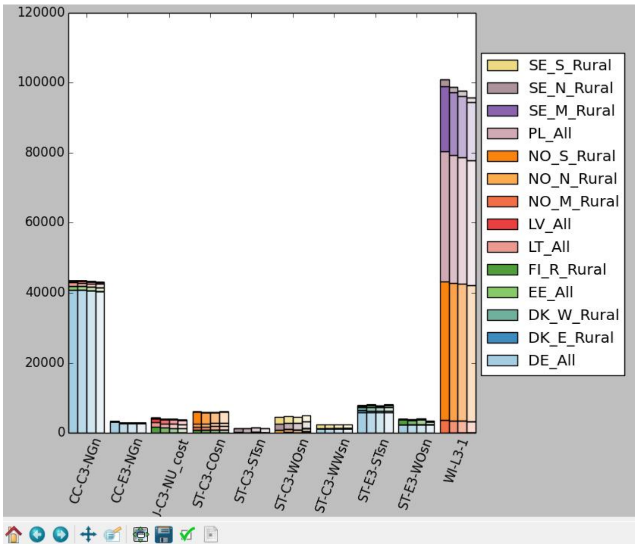

Figure 5. Example of output of capacity investments (in MW) for multiple scenarios, regions and technologies.

Figure 6. Example of output of electric production for new units for multiple regions.

The results for the WILMAR JMM are processed similar to Balmorel. The JMM outputs more detailed results and as a consequence there are more options for plotting.

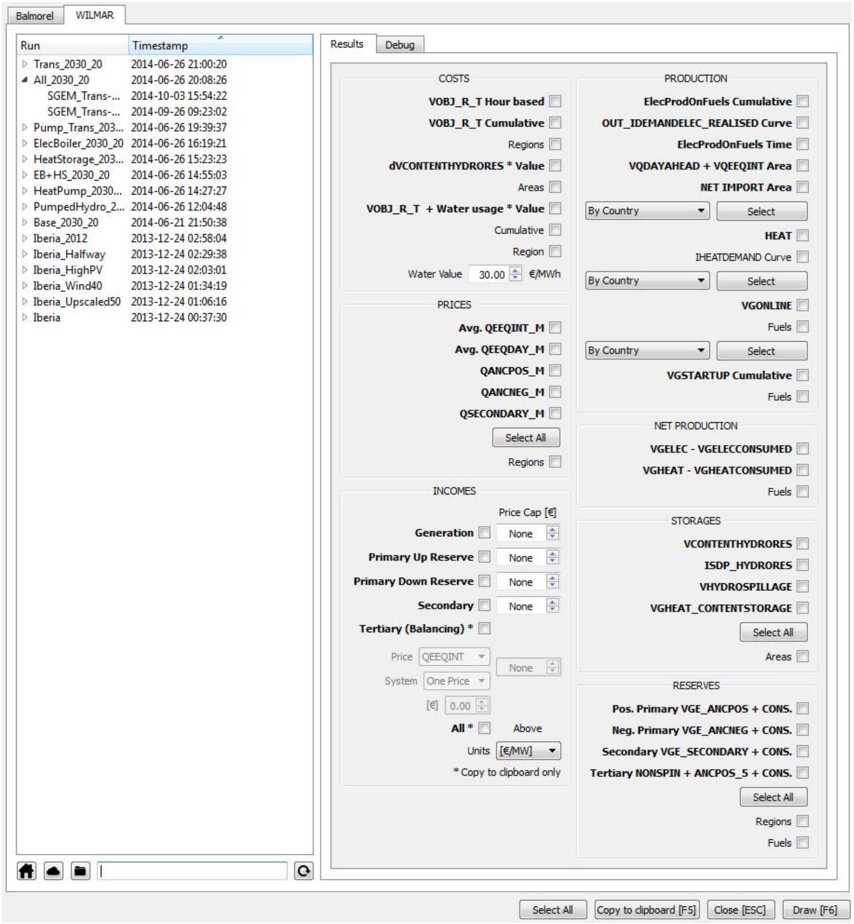

Figure 7. Sceleton's results window for WILMAR JMM simulations.

The results have been grouped in 7 different categories:

- **Costs:** such as operational costs (cumulative and hourly), water's shadow-cost, total operational costs, etc.
- **Prices:** intra-day, day-ahead, primary and secondry reserves' prices.
- **Incomes:** estimated incomes for the produced from various sources, such as generation and reserves.
- **Production:** MWh/h values of production for generation, heat, start-up, etc.
- **Net-Production:** Production values in MWh/h, but considering the consumptions happening in the system, such as the powering up of electric boilers or pumping of hydro reservoirs.

- **Storages:** storage related values such as the content of heat and hydro storages.
- **Reserves:** allocation of different type of reserves, able to be separated by regions and/or fuel type.

There are more options for customizing the plots in the WILMAR side. For instance, the window depicted in

Figure 8 allows user-chosen grouping of fuels, countries, etc. The same functionality will also be added for Balmorel results, as it simplifies the process greatly and outputs simpler data for reporting purposes.

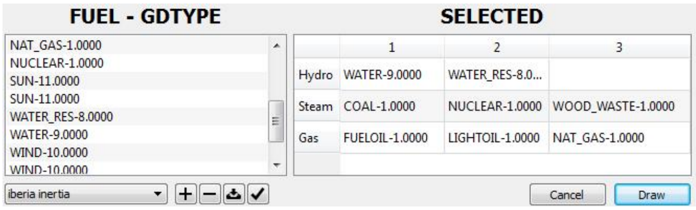

Figure 8. Window for selecting combination plots.

5.4 Data exchange between models

Sceleton has functions to read and write the input and output files of the aforementioned models. It can also convert output from Balmorel to WILMAR (power plant and transmission interconnection investments and their technical characteristics) and from WILMAR to PSS/E (dispatch of power plants and location of loads). The files are either text files with model particular formats or GAMS language binary GDX files. It is possible to add new models to the loop by defining functions that can access particular input and output formats. When running models in conjunction, Sceleton waits for the execution of one model before proceeding to the next. Iterative optimization between models is currently under development.

Further reading

Balmorel – Energy System model, Available at: http://www.eabalmorel.dk/ (Accessed 17.11.2014)

PSS@E – Power Transmission System Planning http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/software-solutions/planning-data-management-software/planning-simulation/pages/pss-e.aspx (Accessed 17.11.2014)

WILMAR – Wind Power Integration in Liberalised Electricity Markets http://www.wilmar.risoe.dk/index.htm (Accessed 17.11.2014)

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