THE COMPUTER-MODELLED SIMULATION OF RENEWABLE ELECTRICITY NETWORKS

Stefan Herbergs, Harry Lehmann and Stefan Peter
ISUSI, Institute for Sustainable Solutions and Innovations, Römerweg 2, 52070 Aachen, Germany,
Phone: +49 241 4095 68-0, Fax: +49 241 4095 68-68, e-mail: hl@isusi.de

Abstract – The computer-modelled simulation of renewable electricity networks is a method for the research and optimization of electricity / energy systems with a high share of renewable energy suppliers. The SimREN Software offers the possibility to design "close to reality" models of energy supply and demand systems following a "bottom-up" approach. Independent and detailed models for energy demand, energy management, adapted distribution systems and energy supply can be used to study different energy systems relying on renewable sources. A country or island can be divided into 15 regions, each region subdivided in up to 15 sub-regions, each consisting of many different suppliers and consumers. The simulation uses real measured weather data for a complete year with a typical time resolution of 15 minutes for one simulation step. Both supply and demand can be simulated with their dependence from the actual time and weather. With the SimREN System it was possible to study the dynamics of energy systems with a high share of renewable suppliers and to show that a "typical" OECD country could be supplied completely from renewable sources. The simulation helped to develope and optimise the system in order to make supply reliable and keep the technological expense at a minimum.

1. INTRODUCTION

Energy systems must guarantee that energy production always is sufficient to meet demand. Electricity must be produced by the time it is needed. Therefore, in energy supply systems with a high share of renewable energy suppliers, the electrical subsystem is the most (time) critical component. To guarantee electricity supply's reliability it is necessary to prove that production rates always meet demand. A dynamic simulation of the electrical supply system can be used for proving and optimizing such supply systems.

2. THE STRUCTURE OF SIMREN

SimREN is such a dynamic simulation tool, which calculates the energy supply and demand with a certain temporal resolution. It has a bottom-up structure. This means it consist of different elementary blocks that are combined to bigger blocks, which - in total - form the model of the regions or islands whole energy system. An elementary block – for example - could be a wind turbine. Several of them can be combined to form a wind park. These wind parks, together with other energy suppliers and energy consumers, can build a logical region of the whole system. The different energy components yet included in the system are shown in the graph below. The graph also shows the assumed energy flow for a renewable energy system.

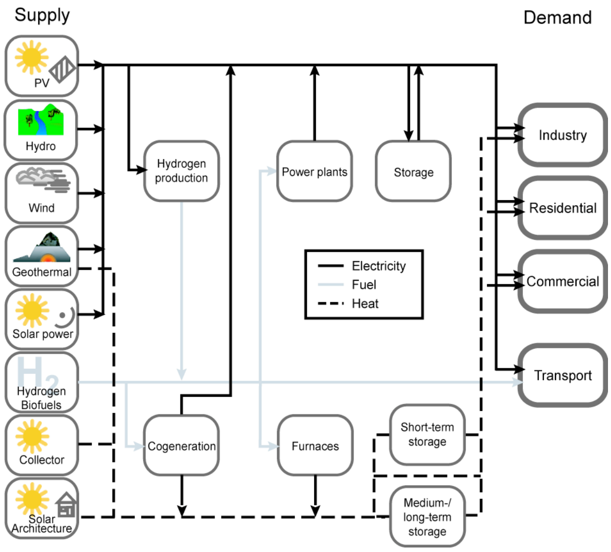

Figure 1: Energy flow in a renewable energy system in SimRen between the included components

The country or island simulated with SimREN can be divided into 15 regions, which can supply each other with energy. So, if one region cannot supply itself with energy and another region already produces more than needed or is capable of producing more, they can exchange energy. The energy manager, which can be set up for different strategies in energy supply, does the task of exchanging energy.

Each region can be subdivided into ten to fifteen sub regions, each consisting of many different energy suppliers and consumers. The energy suppliers are categorized as fluctuating or adjustable energy suppliers (non-fluctuating).

The simulation runs for a complete year with a typical time resolution of fifteen minutes for one simulation step, but shorter intervals are possible as well.
The structure is illustrated in the graph below.

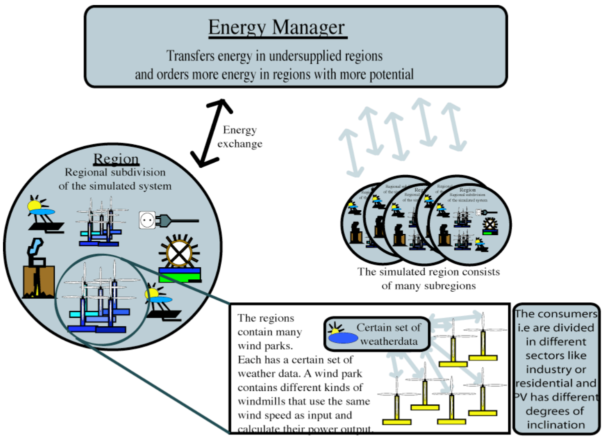

Figure 2: The structure of the SimRen simulation

3. INPUT DATA

SimRen uses a database of real weather data and detailed information about the installed capacities of energy producers to calculate the energy output of certain renewable technologies. Typical demand profiles of days for the different seasons - that is the variation of energy consumption in the curse of a day - are also needed to calculate the energy demand throughout the year. A persistent algorithm in the simulation, which calculates the energy demand and supply at every time step, uses this information.

4. SIMULATION

The simulation consists of four parts:

- Energy Demand
- Energy Supply by fluctuating sources
- Energy Supply by non-fluctuating sources
- Energy Manager / Energy Exchange

First of all the energy demand is calculated.
Secondly the electricity production of fluctuating suppliers in every region is determined and subtracted from the energy demand. The remaining demand is what has to be covered by adjustable suppliers and storages, which are last in the simulation sequence.
The energy manager is in control of the adjustable energy suppliers and keeps track of energy production and consumption in order to properly adjust supply to demand.

5. DEMAND MODEL

The simulation of energy demand is essential to guarantee a good simulation of an energy supply system. It is very difficult to get measured high quality data of a country's energy demand for every hour of a year. Therefore a demand model must be included, which calculates the energy demand for every hour of the year from typical demand profiles.

SimREN can generate the demand for the whole year from typical daily and monthly demand profiles. An example of such hourly demand profile is shown below.

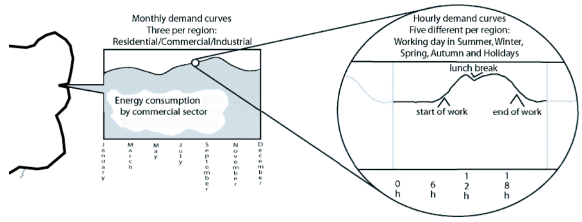

Figure 5: Typical energy demand profiles for a summer working day

A complete set of daily demand profiles (typical working days and holidays of every season of the year) should exist in order to get a properly synthesised and hourly resolved demand profile for the whole year, thus representing the energy demand for every single hour of the year. This kind of data can often be obtained from the energy supply companies. The UCTE webpage for example has daily demand profiles for every participating country. Merging the curves results in the given energy consumption for the whole year, containing the monthly and daily profiles on an hourly base. It is necessary to obtain data for the different sectors of energy consumption, such as industry, households, etc.
All the above mentioned profiles were available for Germany and for a "typical" OECD-country.
Once having completed the demand model SimRen allows for testing different options in energy demand, such as demand management or the introduction of energy efficient technologies.

6. SUPPLY MODEL

SimRen's energy supply model consists of fluctuating (e.g. windenergy and photovoltaics) and non-fluctuating sources (e.g. cogeneration plants, hydropower plants, etc.).
The different energy producers can be freely distributed to the regions of the model to keep the installed capacities well adapted to geographical and climate conditions of a region for every technology included.
An example of regional energy sources is illustrated in the figure below.

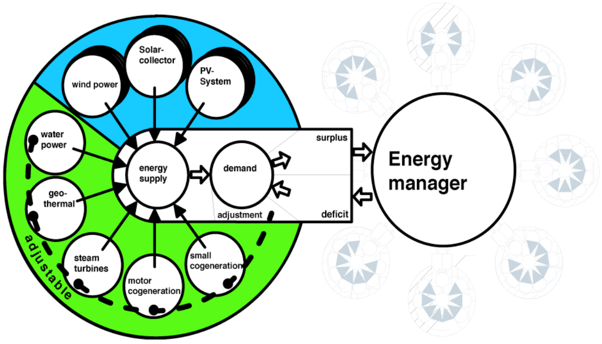

Figure 6: Example of regional energy sources

6.1 Fluctuating Sources

Wind energy and photovoltaic are fluctuating electricity suppliers because they depend on the wind and solar radiation respectively. In addition to these two suppliers, cogeneration plants in the residential and commercial sector can be seen as fluctuating energy suppliers (depending on outside temperature) as the heat needed in these sectors determines the production of electricity. This is different if they are handled as virtual power plants.

6.2 Non Fluctuating Sources

Adjustable energy suppliers used in SimRen include hydropower plants, geothermal power plants, fast reacting power plants and cogeneration power plants for high and low temperature heat. The power output of pumped storage plants is also adjustable but restricted by storage's water level. Because the maximum power output of the hydropower plants fluctuates with water's level of the rivers, the controllable maximum power output is restricted to that.

6.3 Energy Manager

The energy manager of the simulation takes control of the adjustable energy suppliers. This energy manager controls the cogeneration plants, the hydropower plants and the geothermal power plants.

Due to the modular design, the energy manager can follow different strategies in energy supply.

A short example:

Besides producing electricity, cogeneration plants can supply heat at different temperatures (low- or high-temperature heat). If the cogeneration plants are set up to cover heat demand, the simultaneous produced electricity can be used for public supply, increased independece from the public grid and/or the production of hydrogen. If they are adjusted to meet the public electricity demand, the simultaneous produced heat can be used for industrial processes, district heating, etc.

Having control of the adjustable energy suppliers – including storages and backup capacities -, the energy manager can ensure the most rational use of the different technologies according to regional boundary conditions.

The energy manager also has the capability of distributing energy between the different regions. If, for example, one region has got a deficit in energy supply, the energy manager will ask the other regions to fill up the gap. Doing so, the energy manager keeps track of distances between the regions and grid losses caused by transportation to choose the most rational option.

7. RESULTS

The results of simulating a "typical" model OECD country showed the possibility of supplying the energy needs solely from renewable sources. While the energy demand was reduced by the introduction of energy efficient technologies in all sectors of energy consumption, the supply system's technological mix was optimized regarding least amount of installed capacities and greatest reliability in supply. The high spatial resolution gave the opportunity to benefit from specific regional offerings of renewable sources and thus to minimize fluctuations in energy production. The need for backup capacities was minimized as well.

Several simulation runs were used to optimise the system regarding supply's reliability throughout the year. After that the energy supply showed to be as reliable as conventional energy supply systems.

Results of a simulation with SimRen are exemplary shown in the graph below

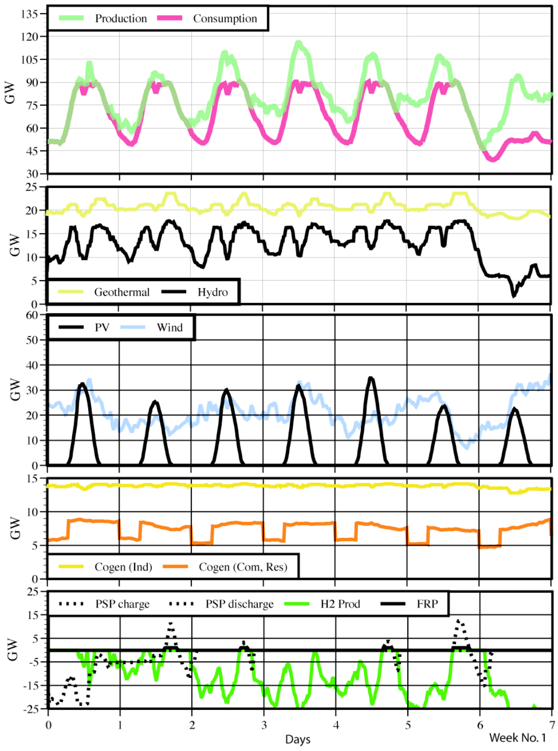

Figure 7: Energy supply and demand of a "typical" model OECD-country for one week

To illustrate the results of SimRen, the graphs above shows the energy production and consumption balance for the first week in January of a simulated 100% renewable energy supply for an OECD country. The first graph (above) shows the energy consumption compared with the production, while the other graphs show how the full supply was accomplished. The second graph shows the adjustable energy suppliers and how their output is regulated to compensate for the fluctuating energy suppliers PV and wind (3rd graph) at times of low production. The 4th graph indicates the heat demand in the residential and commercial sectors, where the cogeneration output can be seen to correlate with the outside temperature. Even powering down the systems during night times is represented by this graph. The output of industrial cogeneration is relatively stable throughout the week. During day 1 and day 5, the discharge of Pumped storage plants can clearly be seen to coincide with a relatively low production of PV and wind (3rd graph). The last graph also contains energy that was needed to fill pumped storage plants and to produce hydrogen.

Graphs of this type, showing the results for every day of the year, also exist for each region of the simulation. The detailed results give the opportunity to analyse regional conditions in depth. This information is also helpful in identifying "hot spots" for future action and thus in developing strategies for extending the share of renewable energy sources

8. FUTURE WORK

The future development of SimRen focuses on an extended functionality of the database and improved data handling.

One of the next steps will be using SimRen to develop renewable energy supply scenarios and strategies with a focus on fuly renewable energy supply.