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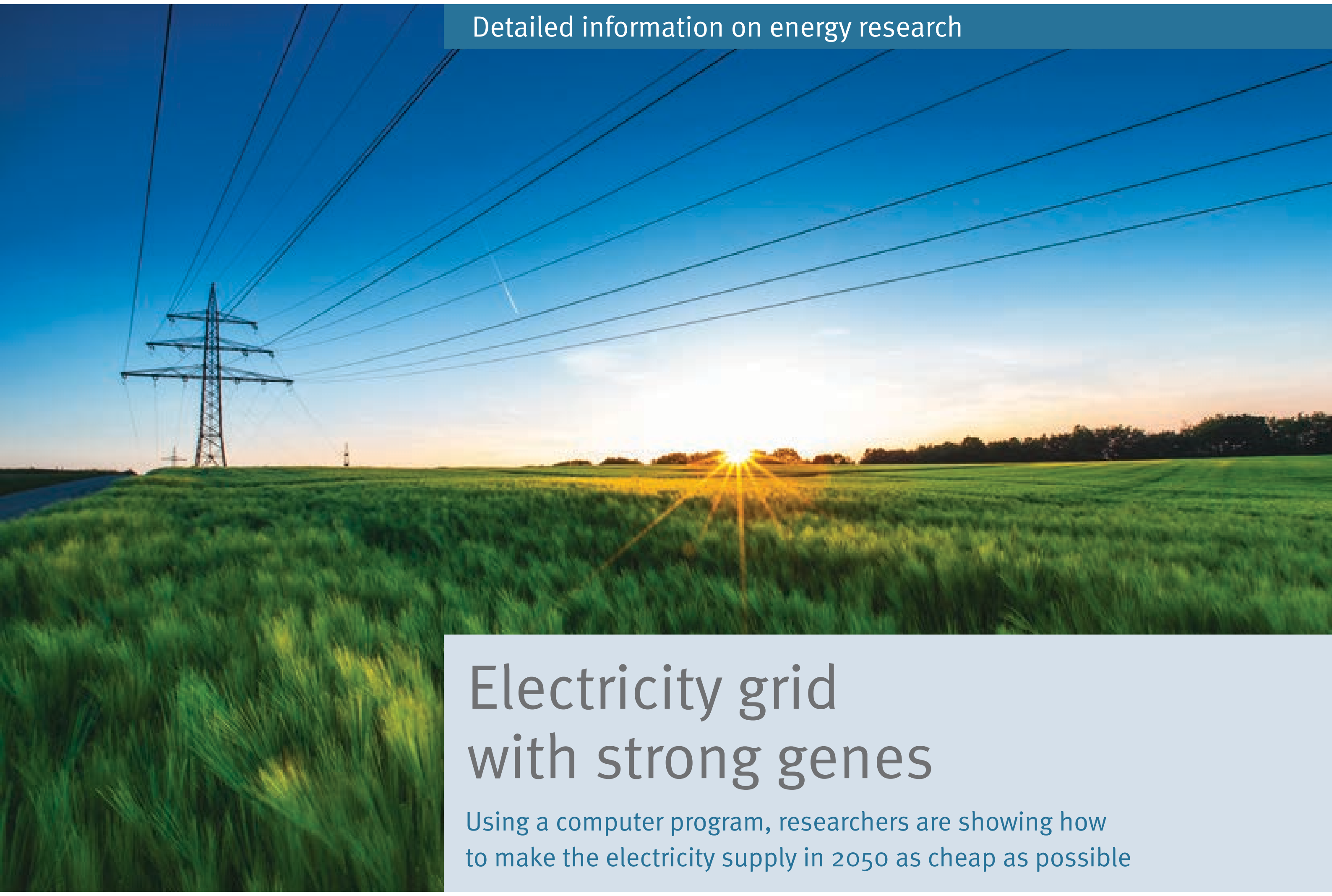
Detailed information on energy research



Electricity grid with strong genes

Using a computer program, researchers are showing how to make the electricity supply in 2050 as cheap as possible

BINE Information Service

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The electricity grid is both dynamic and sluggish at the same time. On the one hand, it distributes electricity with rapidly fluctuating loads. On the other hand it takes a long time before constructional changes can be planned and carried out, which is due to both technical and social reasons. This makes it important to assess future scenarios with simulations. Scientists at RWTH Aachen are achieving this with their GENESYS software program.

The goal of GENESYS is to simulate an electric power system and optimise it with the lowest possible overall costs. The name stands for Genetic Optimisation of a European Energy Supply System. "The software program is mainly aimed at further research, for example, for scientists who want to compute similar projects in other areas," explains project manager Christian Bussar. "In addition, companies could use the forecasts to develop future strategies." The uses and users differ, but the goal remains the same: to save costs.

To provide a base scenario, the developers set the program to create a European energy supply exclusively from wind and solar energy. The cheapest overall costs were achieved with a ratio of 40 % wind and 60 % solar energy for the installed capacity. The price of a kilowatt-hour was less than 10 cents. Based on the price development, the developers assumed investment costs of 1,000 euros for wind energy and 600 euros for photovoltaic systems per kilowatt of installed capacity. The amortisation period is 18 years for wind and 30 years for solar, whereby the yearly maintenance costs amount to two per cent of the total investment. These figures are based on the results from previous studies.

In addition to expanding the energy generators, two aspects are essential if Europe's electricity is to be supplied by wind and solar energy: a well-developed transmission grid and market-viable energy storage systems. In the simulations, the transmission grid overlays the existing AC technology with high-voltage direct current (HVDC) transmission. In addition, short-, medium- and long-term storage systems will be required. These can store energy to meet short-term fluctuations in the grid or for days when there is little wind or considerable cloudiness. With this data, the program can then compute an energy system that satisfies the requirements for achieving supply security and can be constructed and operated as cheaply as possible.

The program responds flexibly to changing conditions

The assumptions for the future power grid and the cost and availability of the individual technologies can be estimated differently by the users. That is why the developers have programmed GENESYS as freeware. Anyone interested can therefore obtain the software free of charge and users can specify the boundary conditions according to their forecasts. A special feature of the program is the observation period. The calculations cover a number of years with an hourly resolution and therefore optimise the energy system at the top grid level. That makes sense for the long-term storage systems used, since the program can suggest precise dimensions.
In the simulation, GENESYS considers individual regions as interconnected units. The HVDC technology enables high capacities to be transported over long distances with few losses. Individual HVDC connections are already used, for example, when connecting offshore wind farms. To achieve functioning interconnections, the DC power cable and converters must be further developed. The overlay network can then feed the distribution grid. From there, the electricity is transferred as usual to the consumers. In this scenario, the connections between two regions had a maximum capacity of 50 gigawatts, but most power lines were considerably below this with capacities of up to 15 gigawatts. In the project, the researchers assumed prices of 77 cents per kilometre and kilowatt for a new HVDC line. If preference were given to other techniques such as extensive underground cable laying, the price would increase accordingly. “The algorithm would respond to higher installation costs and adapt the system. That could result, for example, in a greater expansion of the storage systems or more surplus capacity. In order to maintain the flexibility options, the grid expansion would not be completely stopped,” says Christian Bussar. “However, an increase in prices would be unavoidable.”
It is only when the wind blows and the sun shines that the deployed systems can provide energy. In addition to nationwide balancing by means of the transmission grid, energy storage systems will in future provide temporal load balancing. In GENESYS, the developers are principally relying on gas storage systems. In the base scenario, the program calculated that the total gas storage capacity required amounts to 805 terawatt hours, which corresponds to about 13 per cent of the total annual electricity demand. “If geothermal and biomass power plants are additionally modelled in the simulation, the need for long-term storage systems would, however, be significantly reduced,” explains the project manager. This is because these power plants are controllable. Less energy would then have to be stored for weather-related energy shortages. In southern regions with a high proportion of photovoltaic systems, battery storage systems are also used. Although they have a lower capacity, they have a high efficiency. This makes them suitable for balancing out the unavoidable day-night fluctuations.
A striking aspect is how the relative distribution of wind and solar energy correlate with one another. With an increasing proportion of wind energy the grid moment increases (Fig. 3). This is the product of the capacity and length of all transmission lines. On the other hand, the capacity of short- and long-term storage systems increases when there is a larger photovoltaic proportion. The grid moment, however, then decreases. It only increases again slightly with an extreme scenario when there is 100 per cent photovoltaic energy. However, it comes nowhere near to the value achieved when there is 100 per cent wind energy provision. Put simply, wind energy requires an expansion of the grid, while photovoltaics require an expansion of the storage capacity.

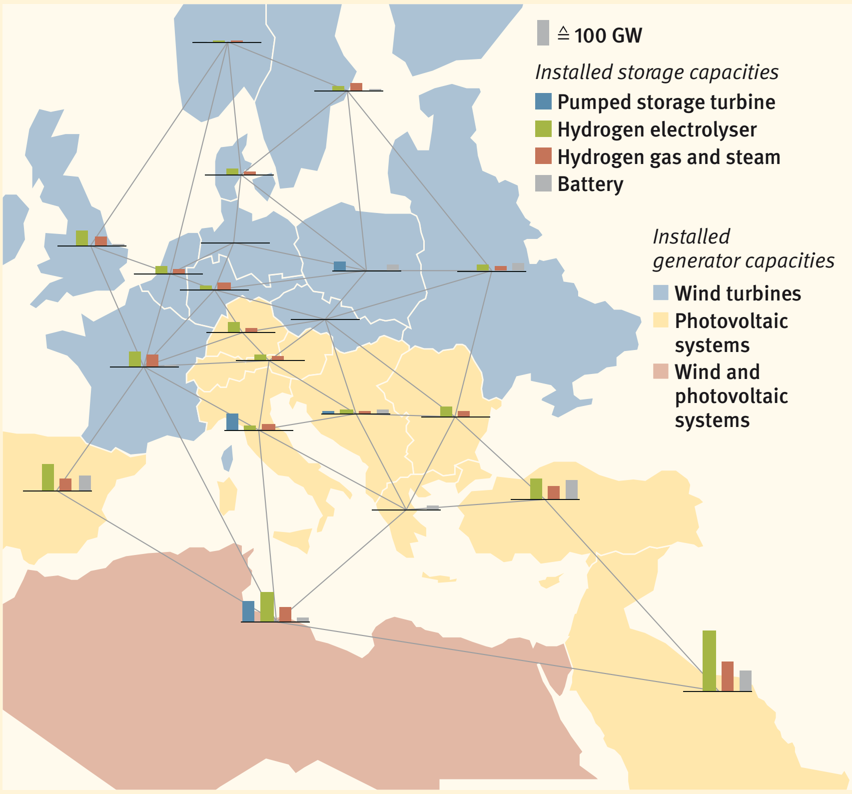

Fig. 1 *The graphic shows an overview of the base scenario. Regions coloured blue represent the use of wind energy, yellow the use of photovoltaics. In North Africa both technologies are used.*

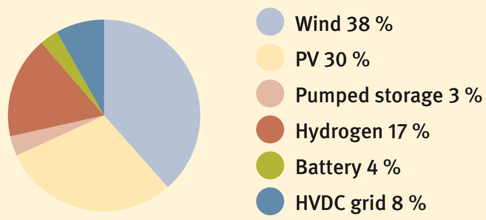

Fig. 2 *The pie chart shows the percentage cost distribution in the base scenario. 30 % of the energy generation costs are caused by PV generation and 38 % are caused by wind generation. Storage systems cause 24 % of the costs and networks 8 % of the costs.*

Biology as a model for calculations

In order to develop a cheap power supply, the researchers seized on concepts from evolutionary theory. In terms of their structure, the genetic and evolu-

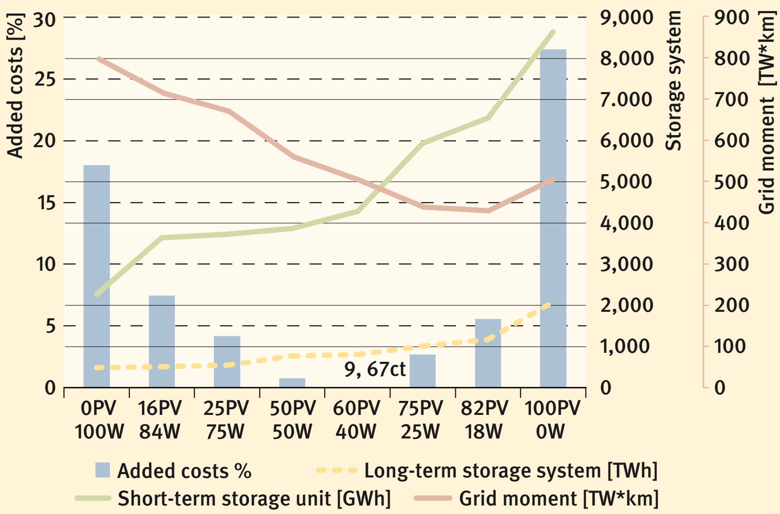

Fig. 3 *The respective variations in the relative production capacity show the additional costs relative to the base scenario and the changes in terms of the storage requirements and grid moment.*

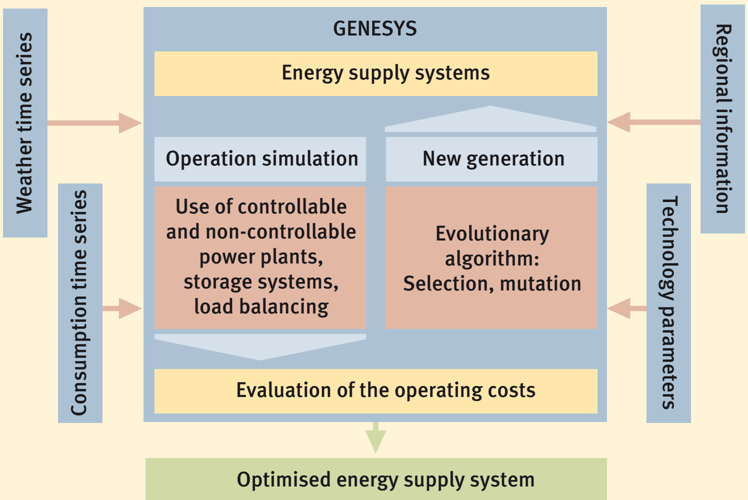

Fig. 4 *The flow chart explains the evolutionary system optimisation using the example of the GENESYS program. The input time series are available in hourly resolution.*

Learning from life

The development of living creatures can also be used to solve technical problems. An example of this is provided by the calculation principles used for evolutionary algorithms. Programmers need only a little knowledge about the system processes and can nevertheless achieve good results. Initially, a first generation receives random values that the system evaluates, and then the system assigns so-called fitness values. These combine with one another so that new values arise. These randomly modify the algorithm and produce modified descendants. Once this process is completed, the results are selected and a new generation is determined. As can be seen in the image, the values (below) are approaching a minimum. The upward outliers are due to the fact that the algorithm is still trying to generate an even lower value with mutations that have not yet been realised.

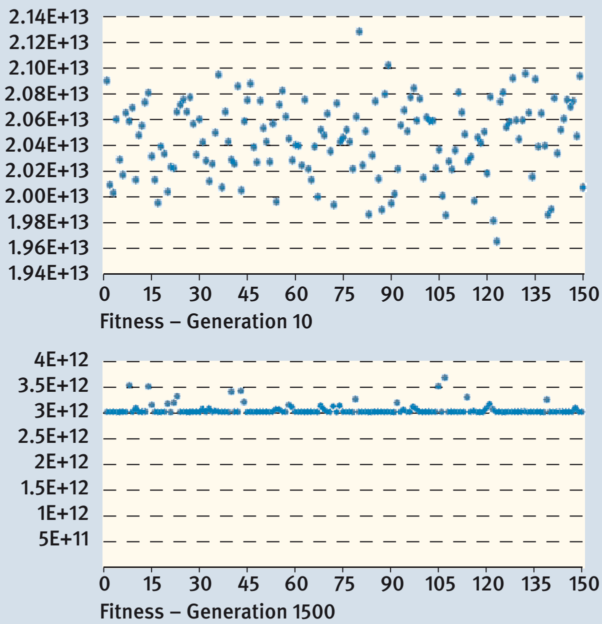

Abb. 5 *The graphic shows the variation of the results before (top) and after (below) the optimisation.*

tionary algorithms used are based on the propagation of genetic information. The stronger characteristics prevail and the subsequent generations have better properties. The defined input data provides the genetic material for the system. The program checks the results of this data and categorises it. It then calculates the cost per kilowatt hour. In subsequent generations, the previously best – i.e. cheapest – results are then adjusted again. After thousands of passes, this results in an optimum. The CPLEX optimisation program provides a reference. The disadvantage is that it calculates in a linear manner. It would take too long to consider a period of several years because the computational complexity would not be manageable.

In addition, GENESYS enables the use of penalty terms. An example: Permanent load coverage is not an absolute prerequisite for future power grids. However, it should not be neglected. To regulate this, there are penalty terms. They considerably reduce a result, for example, when the load cannot be met at a specific time. The program will no longer attempt to optimise in this direction. According to the project manager, this ensures that power outages are as rare in the resulting scenarios as in the current grid. According to official figures, in 2014 these lasted for 12 minutes on average.

Follow-up project already started

Based on the positive results of GENESYS, the researchers have already started the follow-up project. GENESYS2 began in August 2014 within the framework of the “Future-proof Power Grids” research initiative. As part of this project, the original software program will be expanded to include additional modules and functions. For example, it will then be able to calculate how existing distribution grids can be expanded at low cost. Another important aspect is the transformation of the existing supply system. GENESYS2 intends to demonstrate the cost of various development corridors and thus help to create a system that is as economic as possible by 2050. The project will continue until January 2017, whereby the first results should already be available in 2016.

Expanding the grid in Germany

GENESYS calculates technically optimised conditions for expanding the electricity grid. However, the grid expansion is more complex. Germany and Europe are densely populated and transmission cables cannot be simply drawn as straight lines across the country. There are, for example, restrictions on the construction of new transmission lines for environmental reasons. In Germany there is a five-step process for new power lines in order to satisfy all stakeholders.

From scenarios to the construction of transmission lines

First of all the transmission system operators draw up a Scenario Framework and present their assessment of the electricity consumption in 10 and 20 years' time.
This is checked by the Federal Network Agency (BNetzA), which is responsible for regulating the electricity market in Germany.
The subsequent Network Development Plans are more concrete. Here the transmission system operators examine where there is a need for expansion. The construction and decommissioning of generating capacities play a predominant role here. However, societal aspects such as structural developments and environmental impacts are also taken into account.
It is then the turn of the German federal government: it draws up a Federal Requirements Plan (Bundesbedarfsplan) based on the network development plans. This includes the future high-voltage lines. The adoption of the Federal Requirement Plan also establishes that a transmission line will be built.
The Federal Sectoral Planning (Bundesfachplanung) process determines a general transmission corridor including alternatives. The preferred corridor is then determined with public participation.
It is only in the last step, the Planning Approval (Planfeststellung) process, that details such as the actual transmission route and transmission technology are determined. The transmission system operators submit an application, the Federal Network Agency (the competent authority at the federal state level) checks it for environmental impacts, speaks with involved stakeholders and takes a decision on the construction project.
The energy transition will only succeed with further grid expansion. In order to ensure that this is achieved effectively, research projects on grid planning, operation and technology are being carried out, including as part of the "Future-proof Power Grids" research initiative.
More information on the projects is available at http://forschung-stromnetze.info/en/.

Project participants

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Links and literature

- www.genesys.rwth-aachen.de
  Project homepage where the software can be ordered free of charge
- www.forschung-stromnetze.info/en/ The German federal government's research initiative that is funding the follow-up project

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