# AUTOMATIC DESIGN AND OPTIMISATION OF DISTRIBUTION SYSTEMS CONTAINING RENEWABLE ENERGY SOURCES

Roger CREMERS
KEMA – Netherlands
roger.cremers@kema.com

Jos VAN DER BURGT
KEMA – Netherlands
jos.vanderburgt@kema.com

## ABSTRACT

*This paper addresses the development of a software tool that is able to automatically design and optimise electrical distribution systems containing renewable energy sources. The tool is intended to alleviate the task of system designers and analists with regard to the integration of renewable energy sources and use of energy storage systems into their system.*

## INTRODUCTION

Network planners and analists are ever more faced with difficult questions regarding the integration of renewable energy sources into their power systems. To obtain the optimal solution for a particular integration situation they need to make trade-offs between many different, often conflicting objectives like:

- Maximum use of renewable energy sources
- Maximum security of supply
- Minimal investment costs
- Minimal operational costs

To alleviate this task KEMA is developing a software tool that is able to design and optimise power systems automatically.

## SOPRA PROJECT

In 2010 a group of Dutch industries, institutes and utilities have started the SOPRA project [1]. The main objective of this project is to realise a Sustainable Off-grid Power station for Rural Applications. Such a SOPRA system should be able to supply power to isolated, remote areas by making fully use of available renewable energy sources.

Within the SOPRA project a software tool is being developed that is able to design such SOPRA systems automatically while meeting different design constraints and objectives. The tool is partly based on the PLATOS tool [2], a tool developed by KEMA to optimize the use of storage devices in distribution systems.

## TYPICAL QUESTIONS

The conflicting objectives that network designers are faced with eventually result in very tangible questions like:

- What renewable energy sources should be connected to meet the present and future demand?
- What part of the demand can be supplied by renewable energy sources without jeopardising the security of supply?
- Can a storage device help to increase the use of renewable energy sources?
- How to connect the energy sources in an optimal way?

## FUNCTIONALITY OF THE TOOL

The software tool under development offers the following functionality:

- Automatic analysis of actual and future power generation, demand and analysis
- Automatic selection of optimal mix of energy sources (also geographically)
- Automatic design of power system
- Automatic generation of power system model
- Automatic analysis of designed power system
- Automatic optimisation of power system
- Tabular and graphical output of results

This functionality is fully realized within a commercially available power system analysis package with macro programming facilities. No use is made of external packages.

### <u>Functional modules</u>

The software tool consists of a number of functional modules:

- Input module
- Data analysis module
- System design module
- Solution generator module
- Solution assessment module
- Output module

#### Input module

The tool requires certain input data. This data includes:

- Geographical data of area under study
- Data of already existing power systems in the area under study
- Data of projected loads
- Data with regard to potential energy sources in the area under study
- Parameters to be used for the solution assessment
- Assessment period
- Equipment type data (e.g. generators, inverters, PV panels, windturbines)

The geographical data of the potential energy sources is entered into the tool by means of polygons. Each polygon represents an area with a certain energy potential.The polygons can be drawn on an aerial photograph of the area under study. The associated geographical coordinates are automatically extracted by the tool. An example of entered polygons is depicted in figure 1.

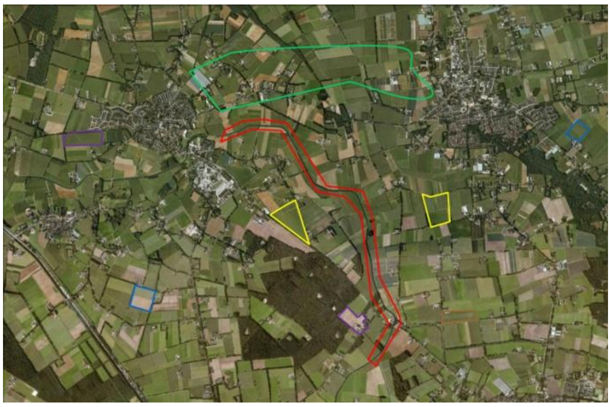

**Figure 1: Area under study with entered polygons**

Besides for entering potential energy sources, polygons are also used to indicate forbidden or preferential zones. In a forbidden zone it is not allowed to construct power connections while in a preferential zone the construction of power connections is encouraged.

In case existing power systems are already present in the area under study, these existing systems can be drawn in the same picture. This is shown in the picture 2 below.

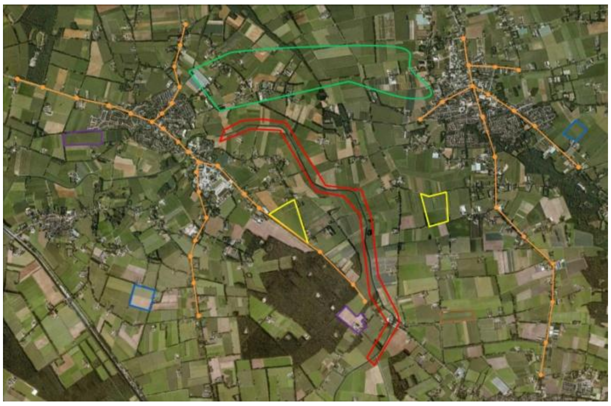

**Figure 2: Area under study with existing grids**

**Data analysis module**
Before a power system is designed all input data is analysed. An inventory is made of the problems that may arise within the planning horizon i.e. the assessment period duration. The inventory tells when a problem occurs, where it occurs and what kind of problem it is.

**System design module**
Based on the entered input data and the results of the data analysis the system design module generates actual designs of power systems. Based on a number of design rules the tool determines what energy sources need to to be connected to the designed system and in what order.

The system design module takes into account numerous parameters that are relevant for the design e.g.:
- Geographical locations of loads, potential energy sources and existing grids
- Load patterns and load growth
- Forbidden and preferential zones
- Typical cost data of the various energy sources
- Required cross section of power connections
- Planning horizon

The generated power system designs are translated in a fully functional power system model. This implies that the system model can immediately be used for various system studies like load flow and short circuit calculations.

Within the single line diagram of the designed power system the various components are shown by means of self expanatory symbols. Some symbols are depicted in figure 3 below.

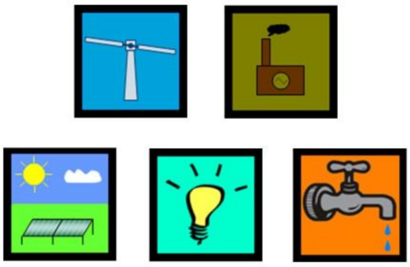

**Figure 3: Used symbols**

**Solution generator module**
The solution generator module generates unique solutions for a given problem. A unique solution consists of concrete values of variables and parameters e.g.:
- Location of windturbines, PV panels, hydro generators and diesel generators to be connected
- Number of windturbines, PV panels, hydro generators and diesel generators to be connected
- Equipment types to be used
- Number, size and power of storage devices to be installed

The solutions are generated by making use of genetic algorithms, a well known artificial evolution technique. The principle of a genetic algorithm is depicted in the figure below:

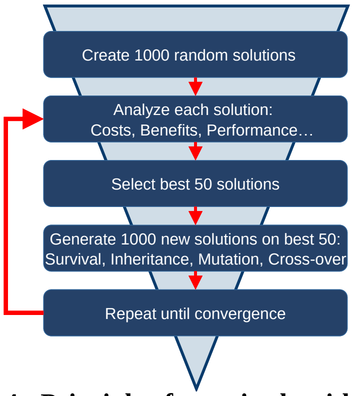


**Figure 4: Principle of genetic algorithm**

Instead of evaluating all possible solutions for a given problem, the tool generates sets of solutions itself. The generation of a new set of alternatives is based on the outcome of the evaluation of previous sets. This process will eventually result in an optimal solution for a given power system and a given set of optimization objectives and constraints, both technical and financial.

The artifical evolution process can be influenced by the user of the tool. For instance the number of generations and the number of solutions per generation can be chosen by the user.

It is also possible to enter so called educated guesses. This allows inclusion of engineering judgement based solutions, proposals from manufacturers or solutions according to company design handbooks. The entered educated guesses are assessed in the same way as the automatically generated solutions.

**Solution assessment module**

The solution assessment module assesses the individual solutions generated by the solution generator module. For each solution an overall performance indicator is determined. The overall performance indicator is based on a number of individual performance indicators.

Each performance indicator is eventually expressed as the Net Present Value of the economic benefit (i.e. benefits minus costs) of the individual solution. Costs include both fixed and variable costs. The fixed costs include the initial capital investment required for the power system connections and the connected energy sources. The variable costs relate to the costs of maintenance, energy losses, life time reduction of storage devices etc.

The benefits of a certain solution are determined by items like:

– Use of renewable energy sources
– Amount of curtailed energy
– Security of supply

The individual performance indicators to be used can be defined and/or selected by the user.

The solution with the highest overall performance indicator is considered to be the optimal solution for a given problem.

**Output module**

All relevant calculation results are presented in tabular and graphical form. The output tables includes all relevant details of the individual solutions. All output data is stored in Excel-sheets.

Many results are also shown in the single line diagram of the existing and generated power systems.

Furthermore it is possible to show a variety of relevant graphs e.g.:

– Plots of produced power of individual sources versus time
– Plots of energy demand versus time
– Plot of relative amount of renewable energy sources versus time
– Plot of curtailed power versus time
– Plots of state of charge of storage devices
– Performance plots of generated solutions

## TOOL VALIDATION

The software tool will be validated within the scope of the SOPRA project. To validate the tool use will be made of measurement data from three pilot projects that will be set up in the Netherlands.

## EXAMPLE

Some design capabilities of the tool under development will be demonstrated below by means of a small study case.

### Description of study case

On a fictitious island the energy demand is increasing rapidly. On several locations on the island new loads are popping up. The island however is only partially electrified. Scattered around the island bigger and small isolated power systems are present.

Also scattered around the island there are numerous potential renewable energy sources: wind, sun and hydro. Some basic data of these potential energy sources is already known.

The fictitious island is depicted in the figure 5 below. The picture shows the already existing grids (in black), the locations of the potential energy sources (the polygons) and the location of the first new load to pop up (indicated by the red arrow).

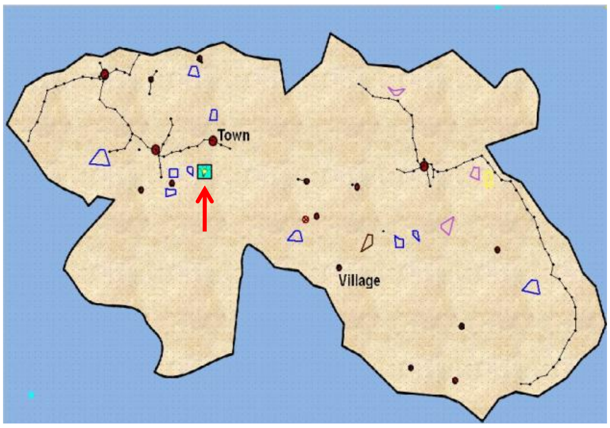


**Figure 5: Fictitious island under study**

The following question needs to be answered:

– Is is possible and feasible to supply the new load via the already existing power systems?

## Results

The answer to this question depends on many parameters. Important ones are the location and size of the projected load. In case the new load is situated near a already existing power system, the system design module tries to connect the projected load to this grid. If there is enough power available in this closest grid the problem is solved. In case there isn't enough power available the system design module tries to interconnect multiple existing grids until enough power has become available. This latter situation is depicted in figure 6 below. The interconnections between existing grids are shown in blue.

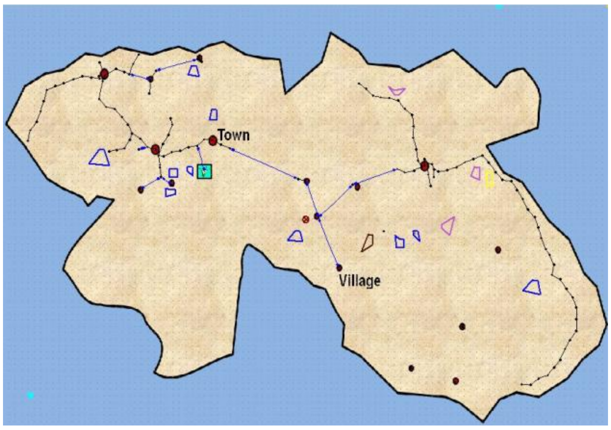


**Figure 6: Load connected to existing grid**

In case the distance between the projected load and the nearest existing grid becomes too large, it is no longer feasible to connect the load to this grid. In this case the system design module will come up with an off-grid power system that makes use of some of the potential energy sources. This situation is depicted in figure 7. The sources to be connected are chosen based on the available power and the associated costs.

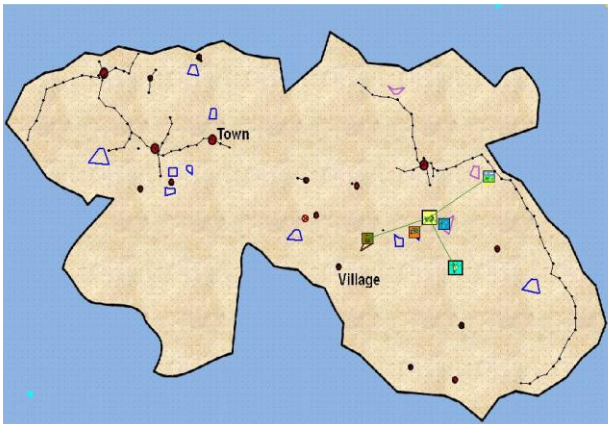


**Figure 7: Load connected to off-grid power system**

## OUTLOOK

In the period to come additional funtionality will be added to the software tool. The objective of KEMA is to include all relevant assessment criteria that are normally used by power system designers and planners. Furthermore the possibility of integrating the PLATOS tool with the SOPRA tool will be investigated.

## CONCLUSION

An innovative power system design tool is being developed that can assist power system planners and analists to provide solutions to problems related to the integration of renewable energy sources. It is believed that the role of 'intelligent' software tools like the one described in this paper will become more important in the coming years.

## REFERENCES

[1] J.J.A. van der Burgt, 2011, "Sustainable Off-grid Power Station for Rural Applications", *Proceedings 6th International Renewable Energy Storage Conference*

[2] R.W.P. Cremers & G.A. Bloemhof, 2011, "Storage optimization in distribution systems", *Proceedings 21st International Conference on Electricity Distribution*, Paper No 0180