Power Optimisation

UNIT COMMITMENT AND ECONOMIC DISPATCH SOFTWARE TO OPTIMISE THE SHORT-TERM SCHEDULING OF ELECTRICAL POWER GENERATION

INTRODUCTION

Electricity generating companies and power systems have the problem of deciding how best to meet the varying demand for electricity, which has a daily and weekly cycle. The short-term optimisation problem is how to schedule generation to minimise the total fuel cost or to maximise the total profit over a study period of typically a day, subject to a large number of constraints that must be satisfied. If the electricity company has responsibility for satisfying the demand for electricity, then the most important constraint is that the total generation must equal the half-hourly forecast demands.

There are two related short-term optimisation problems, 'unit commitment' and 'economic dispatch'. **Unit commitment** is the process of deciding when and which generating units at each power station to start-up and shut-down. **Economic dispatch** is the process of deciding what the individual power outputs should be of the scheduled generating units at each time-point. Unit commitment is a very challenging optimisation problem, because of the astronomical number of possible combinations of the on and off states of all the generating units in the power system over all the time-points in the study period.

Power Optimisation is an independent consultancy, which develops unit commitment software called POWEROP for electricity companies. The software **considers both unit commitment and economic dispatch simultaneously**, which improves the quality of the calculated schedules. The software is **customised** to the **unique features** of the electricity company being modelled and to the **precise requirements** of the user, and it can be **integrated** with the user's own computer systems.

One version of the unit commitment software, developed for Northern Ireland Electricity (NIE), has been used every day since December 1996 to schedule the generating units in the Northern Ireland power system. The users at NIE consider the unit commitment software to be indispensable and they report that the schedules it produces are consistently of a very high quality.

Other versions of the unit commitment software are being used for self-scheduling by a number of generating companies under the British Electricity Trading and Transmission Arrangements (BETTA) in the British electricity market. Each version is customised to the individual requirements of the user.

ADVANTAGES

Back to top

The software is based on a proprietary multi-stage version of a mathematically rigorous optimisation method, the Mixed Integer Linear Programming (MILP) Method. This has the following advantages:

- The schedule produced by the software is **always feasible**, that is it satisfies all the constraints modelled by the software if the data are self-consistent. (If the data or constraints are not self-consistent, then a feasible solution does not exist; in such cases, the less important constraints are relaxed automatically by the software so that a usable schedule is always produced.)
- The schedules produced are better than those that could be found manually or by 'priority-order' methods, **leading to large savings in annual fuel costs and higher annual profits**.
- **A wide variety of constraints and plant types can be modelled**, including complicated scheduling constraints, non-linear cost curves, energy-limited plant, power-purchase agreements and emission constraints.
- It is relatively **easy and quick to introduce new constraints and features** and to modify the software as circumstances change.
- The software is **robust to changes in operating conditions and relative fuel costs**, because no prior assumptions are made about the nature of the solution.
- As a result of using the proprietary multi-stage version of the MILP method, the software finds good feasible schedules much faster than if it were to use the standard MILP method.

FEATURES

Back to top

The objective of the optimisation is to **minimise the total fuel costs** over the study period whilst satisfying the appropriate constraints. Alternatively, the objective of the optimisation can be to '**maximise 'profit'**, defined as the total revenue from electricity sales minus fuel costs. The study period, which is divided into half-hourly time-intervals, can be from a single half-hour up to several days.

The software takes into account **any combination** of the following features and constraints of the power system being modelled:

Types of Generating Units

Back to top

The software can model the operation of both **thermal and hydro-electric** generating units and of **electricity contracts** with other companies. Thermal units can include coal-fired, oil-fired, gas-fired and nuclear-powered steam turbines, and combustion turbines burning distillate (often called gas turbines). Thermal units can also include **dual-fired** generating units, which can burn one of two alternative fuel types. The software can model and optimise the use of **mixtures of different fuels** and/or **gas contracts** in the same generating unit or group of units. The hydro-electric units can include **conventional hydro** units and **pumped storage** units. Gas-fired units and hydro-electric units are treated as **energy-limited plant**. Upper or lower energy limits may also be applied to other types of generating units and may be used, for example, to represent limited fuel supplies or 'take or pay contracts'.

System Constraints

Back to top

- The total output of all the generating units must be equal to the forecast value of the **system demand** at each time-point. The penalty for not doing so is set by the user, so this constraint may be made 'hard' or 'soft' depending on the user's requirements.
- The total spinning-reserve from all the generating units must be greater than or equal to the **spinning-reserve requirement** of the system. This can be either a fixed requirement in MegaWatts (MW) or a specified percentage of the largest on-load output of any generating unit. Again, the user can choose how strongly to enforce

this constraint. The purpose of the spinning-reserve requirement is to ensure that there is enough spare capacity from the units on-load or 'spinning' at any time to cover the accidental loss of any individual generating unit, or to satisfy demands that are higher than their forecast values. The precise definition of how much spinning reserve a particular unit supplies can be customised to the user 痴 requirements.

- The software can also impose a requirement for **30-minute reserve**. This is spinning reserve plus the total capacity of off-load quick-start plant that can be started-up and dispatched within 30 minutes of an emergency. (The latter is sometimes called **standing reserve**.)
- The software can also impose a **negative-reserve requirement**. This ensures that there are sufficient generating units running above their Minimum Stable Generation levels at all times to allow the total output to be quickly reduced by a specified number of MW. (There may be a variety of reasons for such a requirement - for example to cover the possibility of demands being lower than their forecast values.)
- The software can **equalise the outputs of identical generating units** at any one time, but only if this does not cause violations of any other constraints.

Transmission Constraints

Back to top

- The user can define groups of generating units which are in export or import-limited **transmission-constrained zones**. The total import or export of power from these zones must be less than or equal to the specified transfer limit, after taking into account the forecast local demands in the zones.

Cost Characteristics of Generating Units

Back to top

- Each generating unit has a **'no-load'** or fixed **operating cost** and a number of **incremental operating costs**, which can define a non-linear profile of operating costs. These costs can alternatively be expressed as fixed and incremental **heat rates** multiplied by a **fuel cost**, in which case the fuel costs can vary over the study period. The incremental costs or heat rates do not have to be monotonically increasing.
- Each generating unit has either a single **start-up cost** or a number of **warmth-dependent start-up costs** corresponding to a number of warmth conditions of each generating unit (e.g. hot, warm, cold) as determined by the time that unit has been off-load.
- Also modelled is **works power**, i.e. the power taken from the electricity grid when running a particular generating unit or before a generating unit is synchronised with the grid. Like start-up costs, works power can be **warmth-dependent**, depending on the warmth condition of the generating unit when it starts up, as determined by the time that unit has been off-load.

Scheduling Constraints on Individual Generating Units

Back to top

- Each generating unit can have **minimum on and off times**.
- There can be **upper limits on the numbers of start-up events** of each generating unit. These are expressed as a limit on the number in each 'day', where the first 'day' begins at the study start.
- The user can specify **inflexible running** of generating units. This forces a generating unit to run over a specified time-period, with an output not less than a specified value, provided that the system demand is greater than a specified value (which can be zero). Alternatively, the output of a generating unit can be forced to take a specified value over a specified time-period.

Dispatching Constraints on Individual Generating Units

Back to top

- When a generating unit is on, its power output must be at or above its **Minimum Stable Generation** value, except when the generating unit is starting up or shutting down.
- The output of a generating unit must not exceed a specified **maximum value.**
- The user can specify **capacity restrictions** on generating units. These reduce the maximum outputs of the units over specified time-periods. Alternatively, the user can specify different values of the available capacities of generating units in different time-periods (this is called 'profiling the availabilities').
- Each generating unit has **multiple-segment spinning-reserve characteristics** which depend on the output of that unit.
- Generating units can be subject to **warmth-dependent run-up rates**. When such a unit starts-up, it begins operating at a power output below its Minimum Stable Generation, and it runs-up to Minimum Stable Generation by following a warmth-dependent non-linear run-up profile, depending on the time that the unit was previously off-load.
- Generating units are subject to maximum **loading and deloading rates** when running above Minimum Stable Generation. There can be more than one loading rate for each generating unit, and the user can specify MW values for breakpoints which define the output values at which the applicable loading rate changes. In the same way, there can also be more than one deloading rate for each generating unit.
- Generating units can be subject to **run-down rates**. When such a generating unit shuts-down, it follows a non-linear run-down profile below its Minimum Stable Generation.

Station Constraints

Back to top

- There can be **'station synchronising intervals'** and **'station**

desynchronising intervals' at some power stations. These are minimum time gaps between the start-ups and shut-downs of generating units at the same power station.

Dual-Fired Generating Units

Back to top

- Dual-fired generating units **can use one of two different fuel types** at a time, for example either coal or oil, but not a mixture of the two fuels. The software can optimise the scheduling and power outputs of such dual-fired units, taking into account the costs, heat rates and maximum power outputs for each fuel type. Alternatively, the user can force a particular fuel type to be used by a dual-fired unit at any time, for non-economic reasons. When the unit switches from one fuel type to the other, while staying on-load, the software does not impose any start-up costs or run-up profiles on the second fuel type.

Mixed-Fuel Generating Units

Back to top

- Mixed-fuel generating units **can use a continuously-varying mixture of different fuel types** at a time, for example oil and gas. The software optimises the scheduling, power outputs and fuel usage of such mixed-fuel units, taking into account the costs, heat rates and maximum power outputs for each fuel type.

Gas Constraints (or other types of fuel constraint)

Back to top

- Gas generating units may be subject to **energy-limits**, in the form of **minimum and maximum daily takes** of the total gas used at a power station or of individual gas contracts. Such daily energy limits can also be applied to other types of generating unit if desired.

- The gas contracts can be of the **'take or pay'** type, in which there is one price for the gas below the minimum daily take and another price for gas above the minimum daily take.
- There can be **gas from more than one contract** or supplier used at a power station, with each gas contract having its own prices, characteristics and energy limits.
- There can be **minimum and maximum flow rates** of the total gas used at a power station or of individual gas contracts.
- The total power output from all the gas generating units can be limited by a **'gas impact factor'**, which multiplies the system demand at each time-point.

Pumped Storage

Back to top

- The software can optimise the use of **'pumped storage'** hydro-electric units, taking account of the energy lost in the pumping cycle. The software optimises the times and amounts by which to pump and / or generate from the pumped storage units, and when the pumped storage units should be off.
- The water stored in the upper **reservoir** of the pumped storage units can be kept between specified upper and lower limits, to prevent spillage or drainage of the reservoir, allowing for any inflow of water into the reservoir. The user can also specify minimum, maximum and target values for the reservoir level at the end of the study period.   He can also determine how firmly the target level is enforced by choosing appropriate penalty costs.

Electricity Contracts

Back to top

- An electricity contract with another company can be modelled (using the software) as a pseudo-generating unit or as a 'demand' unit. This option offers all the features described above, for example ramp rates, energy limits, and minimum on and off times, which can be useful if the electricity contract contains such features.

For the British electricity market, the software also has an option for the direct modelling of the electricity contracts which are offered on power exchanges or by electricity brokers. Electricity contracts (also known as **power contracts**) may be of type 'buy' or 'sell', The software models the details of the eelctricity contracts that are offered on the British contracts market. Electricity contracts may optionally be grouped, so that if one contract in a group is accepted then all the other contracts in that group must be accepted. This direct modelling of electricity contracts allows the software to consider a much larger number of such contracts than if they were modelled as pseudo-generating units. This provides guidance to the electricity company as to which contracts to accept and at what volumes, in order to maximise profits, whilst taking into account the knock-on effects of accepting those contracts on the outputs of the physical generating units, including the effects of ramp rates.

The software also has an option to meet a particular demand pattern or desired 'Net Contract Position' using electricity contracts only; this option can be used by an electricity trading company that has no generating plant of its own. In this case, the software recommends which electricity contracts are most profitable to accept among the possibly very large number of available contracts, and it identifies **arbitrage opportunities** that may exist but which may be very difficult to find manually.

Initial Conditions

Back to top

- At the user's option, the software can either use **specified values of the initial conditions or it can choose its own initial conditions**. Using specified values of the initial conditions would be appropriate for short-term operational use. The option of letting the software choose its own initial conditions is suitable for longer-term planning.

Import and Export across an Interconnector

Back to top

- The software can be used to optimise the **import and export of power** from and to a neighbouring electricity utility via an interconnector. It can also be used in a 'what-if' mode to evaluate the costs or benefits of proposed power transfers across the interconnector.
- Alternatively, generation and demand may be modelled on both sides of the interconnector, with **user-specified half-hourly values for the limits on the flow across the interconnector**, which then behaves like a transmission constraint. It is also possible to treat the demand requirements as 'harder' on one side of the interconnector than the other.

Minimising Changes from a Previous Schedule

Back to top

- The software has an option to **minimise changes from a previously calculated schedule**, whilst taking account of any changes in demand and plant availability that have occurred since the previous run of the software. This can be useful if circumstances change suddenly, but the system operator does not wish to change many of the previously issued instructions to the power stations.

Discouraging Changes in Outputs

Back to top

- The 'ramping' of generating units, i.e. changing their power outputs, causes wear and tear and increases maintenance costs. The software allows the user to specify a **penalty cost on ramping** each generating unit, which is applied per MW change of output. This discourages unnecessary ramping, and where ramping is needed, the user can indicate a preference for changing the outputs of one generating unit rather than another, by specifying different values for the ramping penalty costs of different generating units.

BETTA VERSIONS

Back to top

Some versions of the unit commitment software have been specially developed for self-scheduling by generating companies under the **British Electricity Trading and Transmission Arrangements (BETTA)** in the British electricity market.

The BETTA versions of the software schedule generating units against half-hourly 'Net Contract Positions' in MegaWatt Hours (MWh). The software can model general market prices for electricity, and can also be used to model individual 'buy' and 'sell' contracts for electricity with their particular characteristics and prices (see the section on electricity contracts above). This provides guidance to traders as to which contracts to accept and at what volumes, in order to maximise profits, whilst taking into account the knock-on effects of accepting those contracts on the outputs of the physical generating units, including the effects of ramp rates.

The BETTA versions of the software calculate minute-by-minute output profiles for each generating unit for the 'physical notifications' that are required under the BETTA rules. These output profiles satisfy the constraints on the generating units, whilst minimising imbalances between the total integrated output profiles and the Net Contract Positions. The study period of the BETTA versions of the software can be up to several days long, with half-hourly time-intervals.

VERSION USED BY NORTHERN IRELAND ELECTRICITY

Back to top

The version of the unit commitment software developed for Northern Ireland Electricity (NIE) has been used every day since December 1996 to schedule the generating units in the Northern Ireland power system. This has a variety of thermal generating units, consisting of gas, coal and oil-fired steam turbines and combustion turbines, and a number of combined cycle gas turbine (CCGT) stations. The total gas used by the gas-fired units and the CCGTs are subject to minimum and maximum daily takes and minimum and maximum flow rates. There are interconnectors with Scotland and southern Ireland.

The software takes account of the complicated operating rules and onerous spinning-reserve requirements of the Northern Ireland power system. It minimises the total fuel cost over the study period of one day divided into 48 half-hours. The users at NIE consider the unit commitment software to be an indispensable tool for scheduling the Northern Ireland power system in the presence of difficult fuel constraints, and they report that the schedules produced by the software are consistently of a very high quality.

USER INTERFACE

Back to top

Power Optimisation can provide a sophisticated user-interface to the unit commitment software, based on Microsoft Excel workbooks. Alternatively, the unit commitment software can be used as a solution engine, which communicates via simple text files with a user-interface developed by the customer.

CUSTOMISATION OF FEATURES

Back to top

Power Optimisation has a policy of customising its unit commitment software to meet the individual needs of the user. In fact, each of the current users has a version of the software that has been tailored to its own requirements. Note that the features described above are the sum total of the features in all of the different versions of the software, rather than in any one particular version.

CONTACT INFORMATION

Back to top

To discuss how this software may be of benefit to your company and for further information,
please contact:

Power Optimisation, Woodside Avenue, Beaconsfield,
Buckinghamshire, HP9 1JJ, England, United Kingdom.

UK Telephone: 01494 675175.

International Telephone: +44 1494 675175.

E-mail: info@powerop.co.uk