Model for CHP operation optimisation

Stane Merše, M.Sc., Andreja Urbančič, M.Sc.

stane.merse@ijs.si, www.rcp.ijs.si/~eec/

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Outline

1. Problem formulation
2. Model definition on TETOL case study
3. Example of modeling approach for Steam boiler characteristics definition
4. Conclusions
Problem formulation

• Key project task:
  – long-term & short-term optimization tool for efficient CHP plant operation in new market conditions

• Optimization objectives (short term)
  – Optimal CHP operation
  – Optimization criterion - economic
  – Considering market environment and uncertainties

Optimization results - deterministic model

• The optimization tool will enable to:
   reduce operation cost (and/or) increase incomes from electricity sales

• by:
   computation of optimal operation load by production units (Load dispatching - Linear programming)
   computation of optimal start up - times (Unit commitment - Genetic alghoritem - GA)
   computation of optimal charging/discharging dynamic of heat storage
Model definition objectives

- to build the system model simple enough to enable application of faster optimisation algorithms,
- to reach the accuracy of the model high enough, to have robust answers on the system optimal response to the changes of varying external parameters in ranges of their expected values,
- to express the model relations in the most general form in order to enable designing the description of the search space which suites the most for GA needs. This is intended particularly to open other modelling options, besides the most known, MILP form for the unit commitment problem.
- time accuracy 1h - static model (dynamic Heat storage)

Modeling approach on TETOL case study

- Scope of the model
  - The TE-TOL (CHP plant Ljubljana) system
  - Deterministic non-linear model
  - Accurate and simple for short term optimization:
    - daily; weekly
  - Extension to the long-term model
  - Heat demand - planned
  - Status of TE-TOL on the electricity market:
    - fixed contracts, preference dispatching, efficiency constraints
MODELLING ISSUES ADDRESSED

• Non-linearity
  – Boiler characteristics non-linearity's
  – Heat sub-stations capacities/dependent on external parameters (distribution heat system return temperature, which can not be optimised)
  – Sensitivity analysis to start-up costs (lack of appropriate data - constant estimate)

• End of interval values
  – Heat storage boundary conditions
  – Qualified electricity producers status compliance (efficiency constraint)

TE-TOL CHP system

• Boilers (B)
  – 3 coal steam boilers (B1, B2, B3)
  – 2 fuel oil peak-load steam boilers (B6, B7)
  – 2 fuel oil peak-load hot water boilers (B4, B5)

• Steam turbines (T)
  – T1, T3 - Extraction condensing
  – T2 - Back pressure extraction

• 2 steam extraction levels (8.5 bar and 2.5 bar)
• Heat storage unit (SU)
• Heat exchangers (HE) – high & low pressure (LP1, LP2, HP1, HP2)
• Steam demand (8.5 bar) and hot water demand
**TE-TOL model elements**

- **Equations in optimization:**
  - I/O characteristics: boilers, turbines
  - dynamic model: heat storage
  - constraints - unit bounds (min/max)
  - heat balances by pressure level
- **Parameters:**
  - data from available measurements (on line, unit’s documentation, etc.) were used

**Mathematical models/ devices**

**Identification and selection of approximation options:**

- **Boiler characteristics**
  - constant (auxiliary boilers) / linear (main boilers) / piece-wise linear (tested) / quadratic
- **Turbine characteristics**
  - linear / piece-wise linear / quadratic
  - sum of extraction flows / separate flows by extraction level (for steam turbines)
- **Boiler start-up costs**
  - constant / linear / piece-wise constant / exponential
- **Heat station bounds**
  - constant / linear / piece-wise linear / other: constant - varying by time interval with temperature forecast
STEAM BOILERS

Variables
- Q ... flows
- s ... ON/OFF status

Characteristics and bounds
- I/O characteristics: \( Q_{\text{fuel}} = f(Q_{\text{out}}) \)
- technical minimum/maximum
- gradients
- minimal on and off time

In cost function
- fuel costs
- variable O&M (non-fuel) costs
- start-up costs (fuel related)

Approximation options
- \( L/PWL, \) fuel costs,
- \( C, \) start up costs

Technical parameters
- efficiencies were determined by an indirect method from measured data
- gradients from operation manual
- off-time: TE-TOL data

Cost function parameters
- fuel, O&M costs approximated from annual values
- start costs - current estimate

BOILER EFFICIENCY
data collection and modelling

Efficiency determined by indirect method from measurements

Influencing parameters
- outdoor temperature
- flue gases temperatures
- \( O_2 \) in flue gases
- output mass flow

I/O curves derived from efficiency
1) point-wise
2) from quadratic fit of efficiency
BOILER I/O CHARACTERISTICS

- Linear approximation (L):

\[ Q_{FUEL}(t) = a \dot{Q}(t) + bO(t) \]

- Piece-wise linear approximation (PWL):

\[ \dot{Q}_{FUEL}(t) = \sum_{i=1}^{N} k_i \dot{Q}_i(t) + c_0 O(t) \]

The impact of L & PWL differences on optimisation results (MILP)

Heat and electricity production

2/12/2003  JSI  Energy Efficiency Centre

3-12/2003  JSI Energy Efficiency Centre
Comparison of results

- Optimal solutions were equivalent for both cases:
  - same optimal cost function value, electricity production,
  - amount of heat storage in-outflow over period,
  - some differences between hours: similar operation status have changed the time of occurrence,
  - some difference in heat contents at the end of period (due to shift of production between hours).

- Conclusion:
  - Optimisation results as well show that linear fit is accurate in a sense that, the improved fit by a piece wise function do not affect the optimal result.

HEAT SUB-STATIONS - capacity limits

- Capacity limits at heat sub-station:
  - Low pressure heat exchanger capacity limit depends on district heating return water temperature (varying by heat demand, outdoor temperature) and on heat storage water temperature

- Modelling options:
  - Constant/ linear/ piece-wise linear/ other:
    - constant - varying by time interval with temperature forecast - outside the model (model input data)
TE-TOL model – MILP formulation

For each hour:
• 15 independent real variables
• 8 integer (binary) variables
• 44 inequality equations
• 2+1 equality equation (DH, Steam, + Electricity)

Long term model approximation

• less detailed description - reduction of model complexity:
  – linear relations,
  – constant efficiencies (independent from load)
    • difference from 2 to 10%
Conclusions

• **Linear modelling** gives comparable results, but with significant reduction in computational time compared to more detailed non-linear modelling.

• **CHP optimisation problem** was defined as a linear mixed-integer problem (MILP), divided into two sub-problems:
  – unit commitment (UC) - solved using a GA
  – economic dispatch (ED)- by linear programming (LP)

• **Dynamic extensive process** - going on with further model testing and validation, future changes, etc.

• For more details about modeling (equations, etc.), look in **Project Deliverables (D 1.4, D 2.1, D 2.2, …)**

Thank you for your attention!

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