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May 16, 2019

Automated energy efficiency optimization for industrial supply technology

Workshop der Arbeitsgruppe „OR im Umweltschutz“ der Gesellschaft für Operations Research e.V.

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- Fraunhofer IPK
- Production Technology Center Berlin
- Division for automation technology
- Department for process automation and robotics

Slides with notes on second screen: `https://dspdfviewer.danny-edel.de/`

Content

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Content

1 Introduction
2 Concept of the Framework
3 Showcase experiment
4 Optimization, Results and Outlook

Project

Project *EnEffReg* 2016-2019:

- Fraunhofer IPK
- ÖKOTEC Energy Management
- Daimler AG (Berlin)
- Bayer AG (Berlin)
- Thyssen Europe Steel (Duisburg)

Field of application

- Industrial sector
- Supply technology
- New design for machines or new control for efficient operation of existing machines?

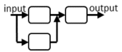
- ÖKOTEC: broad experienced in consulting regarding energy efficiency
- Fraunhofer IPK: Expertise in Automation and Control
- Conventional: find new set-points manually for particular systems using system knowledge

Field of appication

- Industrial sector - huge saving potentials
- Efficiency by design or operation - consider already existing components, Retro-Fitting, new control strategies!
- Supply technology - energy transformation, energy intensive, broad scalability

Requirements

The aim is an approach that:



. . . uses knowledge of topology for systems of systems,

. . . is able to run fully automated,

. . . is broadly transferable to other industrial systems,

. . . allows to utilize a priori knowledge about the systems,

. . . offers periodical updates for all models, restrictions and results.

Requirements
The aim is an approach that:
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. . . offers periodical updates for all models, restrictions and results.

1. Inter-operability: From self-designed Interface to AutomationML
2. Send the optimal value to the control device (from a catalog or online)
3. general methodology and broad framework
4. Sophisticated simulation models are developed in the design phase – could be used in operation!
5. Cyclic update of all models, restrictions and results

EnEffReg-Framework

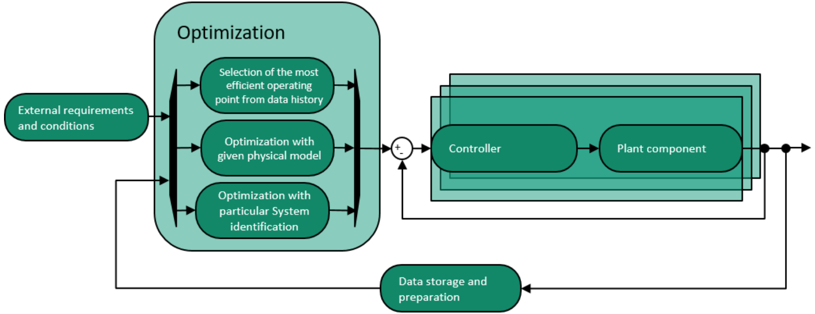

Figure: EnEffReg-Framework for comparative analysis of data-based optimization algorithms [HT16]

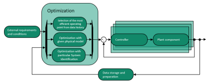

Figure: EnEffReg-Framework for comparative analysis of data-based optimization algorithms [HT16]

- Control loop for set-points
- Additional cascade to the existing control and automation technology
- Interface *Optimizer* can handle and compare different optimization algorithms
- Predecessor project *EnEffCo* leaded to a commercial monitoring system

Control Layer Model

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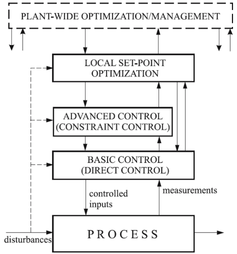


Figure: Tatjewskis control layer model, image source: [Tat10]

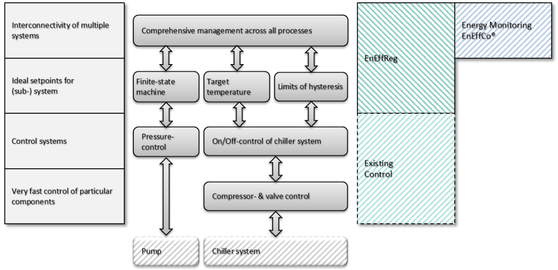
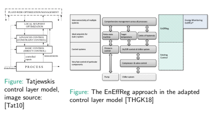


Figure: The EnEffReg approach in the adapted control layer model [THGK18]



- Control Layer Model - Hierarchy of Dynamics
- Cascades: outer loop must not be faster than the inner one
- The set-point can be either a constant value or a timed trajectory
- Identify new degree of freedom which influences machine behavior

Energy KPI methodology

a	factor to weight efforts
α	effort (energy or material flow)
ϵ	efficiency
ϵ_C	efficiency of a single component
φ	adjustable parameter
ϑ	external parameter
n	factor to weight benefits
ν	benefit (energy of material flow)
x	internal state

Table: Nomenclature

$$\begin{bmatrix} \alpha \\ \nu \\ x \end{bmatrix} = f(\varphi, \vartheta) \quad (1)$$

$$\epsilon_A = \frac{\sum_i n_{A,i} \cdot \nu_{A,i}}{\sum_j a_{A,j} \cdot \alpha_{A,j}} \quad (2)$$

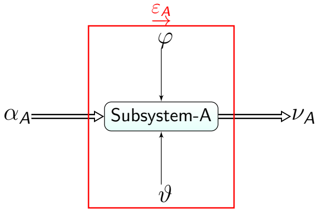


Figure: Sub-system

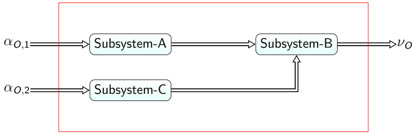
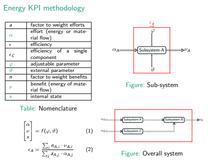


Figure: Overall system



Methodology for

- Definition of efficiency
- Categorization of all quantities
- Common formulation of optimization problem
- Separation of facilities into networks of sub-systems

Cooling system

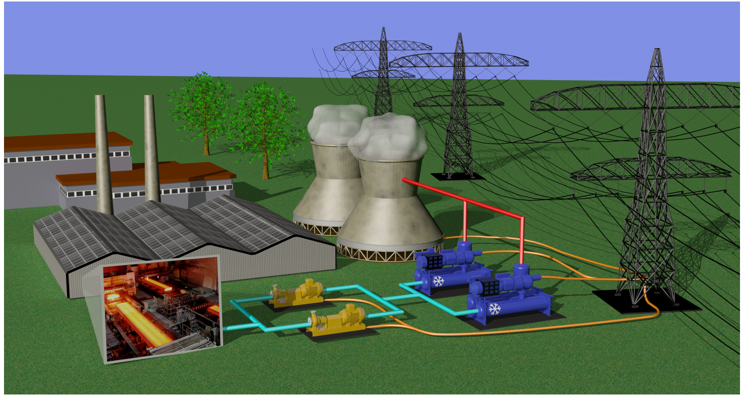


Figure: Cooling system with several optimization problems – [Mil17]

Cooling system

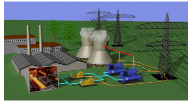


Figure: Cooling system with several optimization problems – [Mil17]

Multiple settings incl:

- target temperature for cooling tower ventilator
- pressure level for pumps in cooled and chilled water cycle
- target temperature for chiller system

Independent optimization of single components is limited – overall optimization including all related systems

Hysteresis Controller

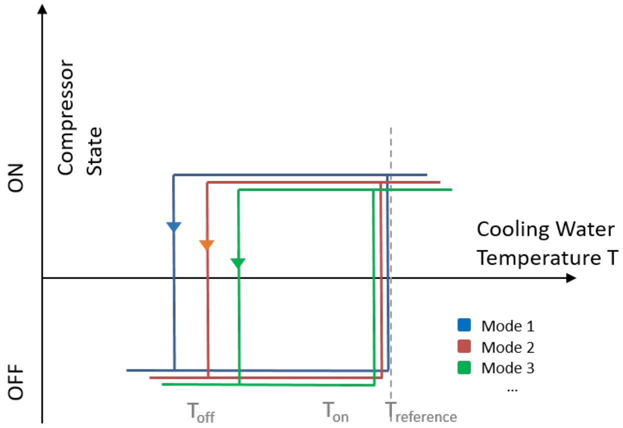


Figure: Characteristics of a hysteresis controller (two-point-controller)

Hysteresis Controller

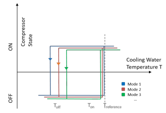


Figure: Characteristics of a hysteresis controller (two-point-controller)

- Avoid oscillations in control
- tolerance zone for binary switchovers

Experiments with hysteresis

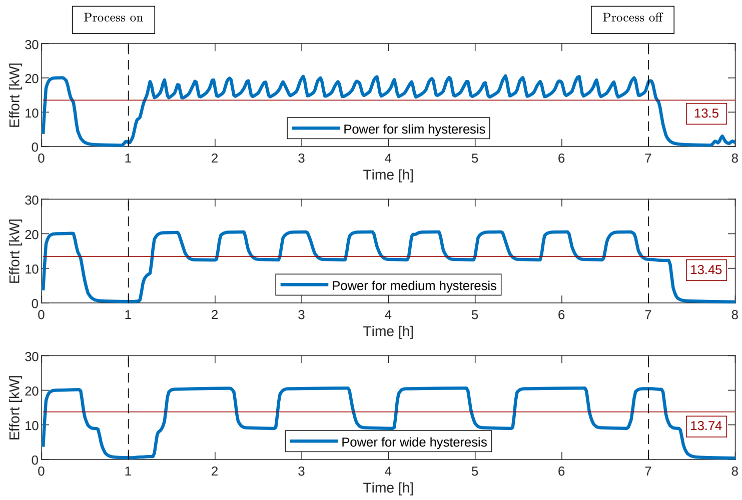
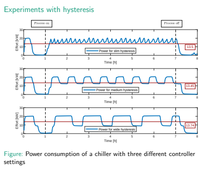


Figure: Power consumption of a chiller with three different controller settings



- Thin hysteresis - losses caused by switchovers + additional wear
- Wide hysteresis - losses caused by high temperature difference (thermal emission)

Optimization modules

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OptimizerZero

- Find suitable norm
- Identify k-nearest neighbors
- Calculate respective efficiency
- Select operation points with highest efficiency
- Check constraints and apply or reject settings

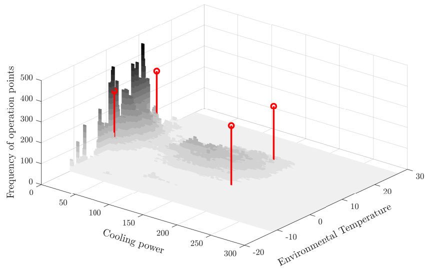

Figure: The empirical standardized unit is deduced from the specific data.

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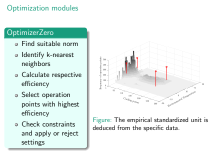
└Optimization, Results and Outlook
└Optimization modules



- conservative approach
- benchmark
- only already known operation points

Optimization modules II

OptimizerOne

Predict (static) system behavior:

$$\begin{bmatrix} \alpha \\ \nu \\ x \end{bmatrix} = f(\varphi, \vartheta) \qquad (3)$$

Evaluate model for all combinations of parameters (φ, ϑ)

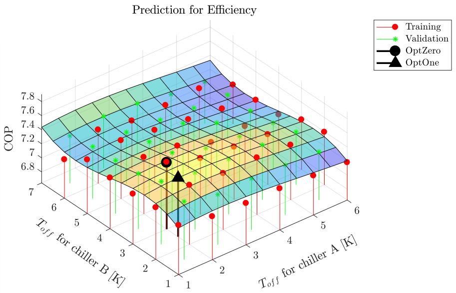
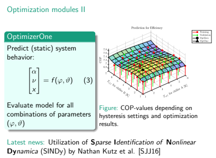


Figure: COP-values depending on hysteresis settings and optimization results.

Latest news: Utilization of ***S**parse **I**dentification of **N**onlinear* ***Dy**namica* (SINDy) by Nathan Kutz et al. [SJJ16]



- No time-dependent values in the formula!
- Set-point influences system dynamics indirectly
- System model: static, polynomials of third order

Current questions and further steps

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Consider dynamics

Model predictive control: Utilization of buffer effects

Standardized interfaces

Utilize sophisticated models from machine design phase:

- AutomationML
- Functional Mockup Interface

Optimization algorithms

- Usage of heuristics for faster computation
- Clustering of strong connections & parallelization of computation
- Agent-based approaches vs. System-of-Systems (SoS)

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- Oliver Heimann and Gregor Thiele, **Ganzheitliche Regelung der Energieeffizienz**, Zeitschrift für Wirtschaftlichen Fabrikbetrieb **111** (2016), no. 11, 710–713.
- Chris Miller, **Optimizing centrifugal chiller systems**, Engineered Systems (2017).
- Steven L. Brunton, Joshua L. Proctor, and J. Nathan Kutz, **Sparse Identication of Nonlinear Dynamics with Control (SINDYc)**, IFAC-PapersOnLine (2016), no. 49-18, 710–715.
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└─Optimization, Results and Outlook
  └─References

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References II

Gregor Thiele, Oliver Heimann, Knut Grabowski, and Jörg Krüger, **Framework for energy effciency optimization of industrial systems based on the Control Layer Model**, Procedia Manufacturing **16th Global Conference on Sustainable Manufacturing** (2018).

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