IMPROVING SAFE OPERATION OF ORGANIC RANKINE CYCLE UNITS IN AUTOMOTIVE APPLICATIONS USING MODEL PREDICTIVE CONTROL

Andrés Hernández[a,b], Shilp Dixit[c], Chris Criens[c], Ludovic Guillaume[b], Davy Maes[c], Ilja Siera[c], Robin De Keyser[a,c], and Vincent Lemort[b]

[a]Department of Electrical energy, Systems and Automation, Ghent University, Belgium
[b]Thermodynamics Laboratory, Energy Systems Research Unit, University of Liege, Belgium
[c]Flanders Make, Lommel, Belgium

Highlights: A major limitation for using organic Rankine cycle (ORC) power units, for waste heat recovery in automotive applications, is the difficulty to guarantee the optimal and safe operation of the unit for different driving cycles. In this study, it is illustrated that Model Predictive Control (MPC) can successfully satisfy these conditions for three typical driving conditions as encountered in heavy duty trucks.

Key words: Organic Rankine Cycle, Model Predictive Control, Automotive applications.

EXTENDED ABSTRACT

Introduction

Implementing organic Rankine cycle (ORC) systems to recover waste heat from exhaust gases, is a promising technology which could enable us to reduce fuel consumption and gas emissions. A possible limitation is however the challenge of keeping the cycle operating safely and optimally during different cycle conditions [1]. In this regard, Model Predictive Control (MPC) appears as a natural solution since it can handle multivariable constrained problems in a very efficient manner [2].

Process description

A reliable dynamic simulation model is implemented in Amesim for the Rankine cycle configuration in Fig.1a, where waste heat is recovered from exhaust, while using ethanol as working fluid. Three driving cycle conditions are chosen as typical examples of conditions encountered on long-haul truck applications: flat, rolling hill and hilly driving cycles [3]. Strong variations in the exhaust temperature and mass flow are expected, thus endangering the system safety and therefore representing the main challenge for the control strategy.

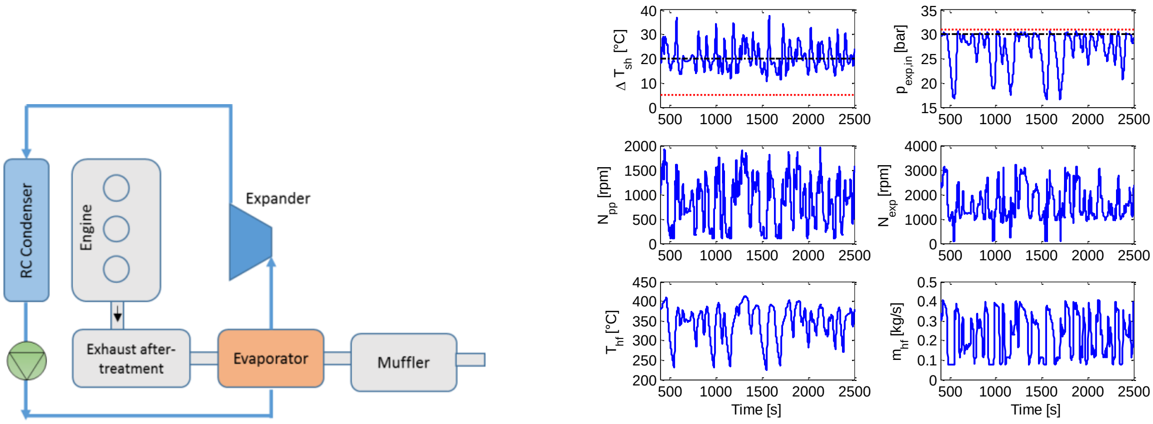
Model Predictive Control (MPC)

MPC refers to a family of control approaches, which makes explicit use of a model of the process to optimally obtain the control signal by minimizing an objective function:

$$\min \quad J = \sum_{k=N_1}^{N_2} [r(t+k|t) - y(t+k|t)]_Q^2 + \sum_{k=0}^{N_{u-1}} [\delta u(t+k|t)]_R^2 \tag{1}$$

where $r(t+k|t)$ represents the reference, $y(t+k|t)$ the predicted output, and $\delta u(t+k|t)$ the decision variable. The main tuning parameters of the MPC controller are the prediction horizons N_2, N_1, the control horizon N_u, and the weighting factors Q and R.

The Extended Prediction Self-Adaptive Control (EPSAC) approach to MPC, is here selected since it uses input/output models for prediction, thus avoiding the need of using state estimators. Discrete-time transfer functions representing the dynamics from inputs: pump speed N_{pp} and expander speed N_{exp} to outputs: superheating ΔT_{sh} and expander inlet pressure $p_{exp,in}$, are identified. The effect of the temperature, $T_{hf,}$ and mass flow, $m_{hf,}$ of the waste heat hot fluid on the outputs are also identified, and further used by MPC as measured disturbances to enhance closed-loop performance The main target for the controller is to operate as close as possible to the maximum expander inlet pressure, to maximize the *net* output power $W_{exp,net}$, while keeping superheating into the safe limits. Output constraints ΔT_{sh} > 5 °C and $p_{exp,in}$ < 32 bar are considered in the MPC formulation, to guarantee safe operation. Results obtained for a rolling hill driving cycle are depicted in Fig.1b.



a) Waste heat ORC system architecture *b) Control performance rolling hill driving cycle*

Fig. 1. Waste heat ORC system architecture and MPC performance for a typical driving cycle

Conclusions

In this study a Model Predictive Control (MPC) strategy is designed and implemented in order to guarantee optimal and safe operation of an organic Rankine cycle power system mounted on a heavy duty truck. Simulation results on three typical driving cycles suggest that the proposed strategy is able to maximize the output power by operating close to the maximum expander inlet pressure, while keeping the cycle in safe conditions. Future work includes the development of a control strategy for parallel configuration, where the exhaust gas recirculation (EGR) is also considered.

References

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Background of the research and development team

This research was supported by Flanders Make, the strategic research center for the manufacturing industry, Belgium.

Andres Hernandez received his B.E (Electronic engineering) and the M.Sc. degree (Control Engineering) from University of Ibague, Colombia. He is currently Ph.D. researcher at Ghent University and University of Liege, Belgium, working on the control design for ORC waste heat recovery systems.

Shilp Dixit completed his B.E (Information Technology) from University of Mumbai and MSc (Automotive Technology: Dynamics & Control) at Eindhoven University of Technology. He is currently working at Flanders Make and focusses on dynamics & control of vehicles and control design for ORC waste heat recovery systems.

Chris Criens obtained his MSc (control systems technology) and PhD (air-path control of clean diesel engines) at Eindhoven University of Technology. He is currently working at Flanders Make, where he works on model based design of ORC waste heat recovery systems and hybrid drivetrains.

Ludovic Guillaume is a PhD. student at the University of Liège (Belgium), where he is working within the Energy Systems Research Group (Thermodynamics Laboratory). He has been working on waste heat recovery from engines since 2011, in collaboration with Industry and in the frame of public funded projects (FP7 Nowaste project). He contributed to the simulation and the testing of many ORC systems and components.

Davy Maes studied electronic engineering, specialization ICT, at KH Kempen. Since 2011 he is working as a project manager at Flanders Make where he is leading research projects on model-based systems engineering and energy efficient system design.

Ilja Siera obtained a BsC in aeronautics at Haarlem UoT, The Netherlands and a PhD at Imperial College London (Optical characterisation of coal fired flames for the reduction of emissions). He is a senior research engineer at Flanders Make in the domain of clean and energy efficient vehicles.

Robin De Keyser is currently full Professor of Control Engineering at the Faculty of Engineering, Ghent University. He is one of the pioneers who produced the original concepts of predictive control during the 1980's. His teaching and research activities include model predictive control, auto-tuning and adaptive control, modelling and simulation, system identification.

Vincent Lemort is an Assistant Professor at the University of Liège (Belgium), where he is leading the Energy Systems Research Group (Thermodynamics Laboratory). He has been working on waste heat recovery from engines since 2005, in collaboration with Industry and in the frame of public funded projects (FP7 Nowaste project). His team has contributed to the simulation and the testing of many ORC systems and components.