MODELLING AND SIMULATION OF THE ELECTRIC ARC FURNACE PROCESSES

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PRESENTATION OVERVIEW

- study ideas, goals and challenges
- electric arc furnace process modelling
- available operational data
- model validation and simulation results
- further research
- other work

Ideas, Goals and Challenges

Ideas

- avoid fluctuations in EAF operation:
  - raw material diversity
  - operator's experience (increased consumption of energy, materials and additives, lower steel yield, ...)
- optimize the EAF melting profiles

Goals

- to design and develop:
  - a complete EAF-process model, including electrical, chemical, thermal and mass-transfer processes
  - an EAF simulator
  - an EAF operation support tool, including EAF soft sensors and optimization framework

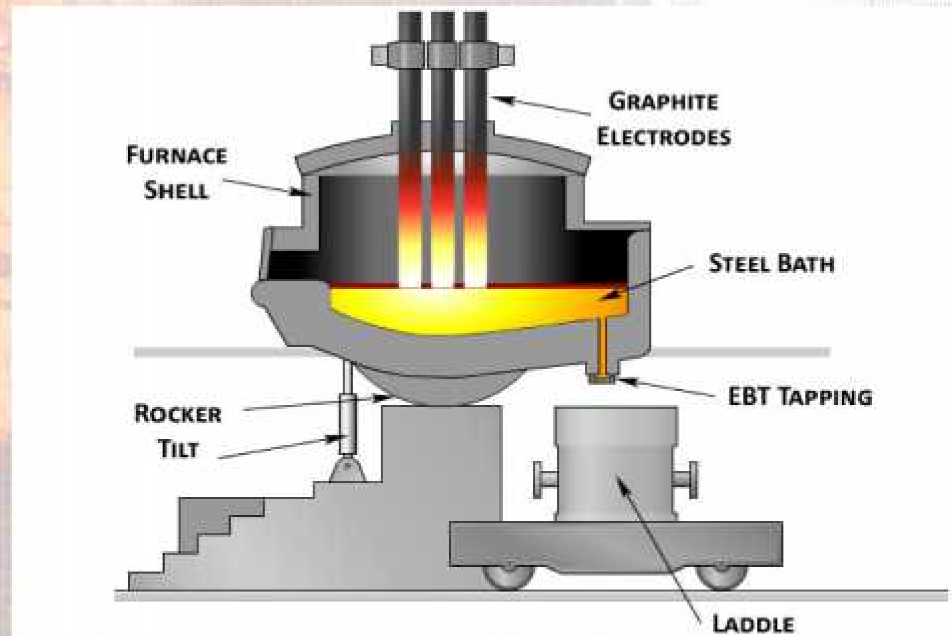
Challenges

- incomplete process measurements (temperatures, steel composition)
- many unknown or hard-to-model mechanisms
  - simplifications

INTRODUCTION TO ELECTRIC STEELMAKING

WHAT IS EAF?

- electric furnace for recycling the steel scrap
- melting of the scrap using electric arcs burning between electrodes and steel



- electrical current through air (50 - 100 kA)
- conduction in high-temperature conditions and initial ignition (short circuit)
- using high temperatures to melt the steel (4000 - 6000 K)

EAF PROCESS MODELLING

MODELLED EAF

- 80 MVA, 3-phase AC EAF
- transformer 600 - 1000 V (18 taps), 47 - 62 kA
- approx. 100 ton capacity
- annual production approx. 400.000 tons
- oxy-fuel burners, no CO postcombustion, no bottom stirring

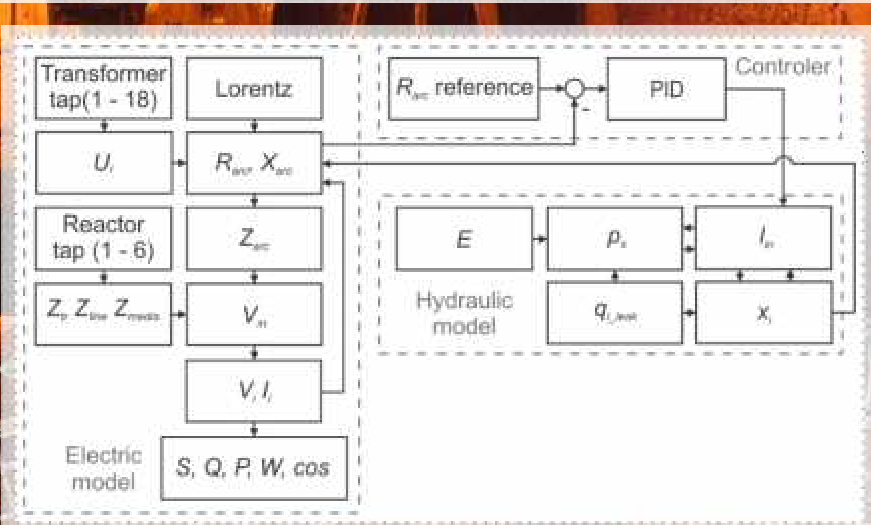
- mathematical models based on fundamental physical laws and empirical additions where possible (availability of the data)
- parameterization using available online and endpoint data (including the conclusions of different EAF studies)

- more than 60 main differential equations
- more than 100 process values

EAF Process Modelling

Electrical and Hydraulic Model

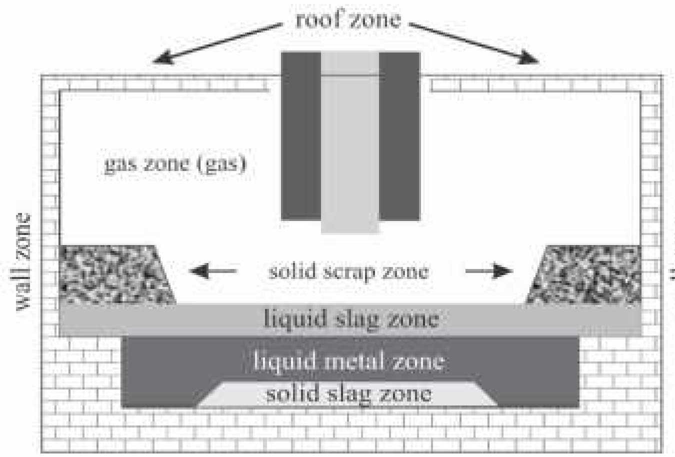
- harmonic analysis (complex space)
- Cassie-Mayr arc model (1st order ODEs) with variable Lorentz noise
- electrode control using hydraulic model with PID controllers
- variable model parameters for different stages of the melting process



EAF Process Modelling

Heat-Transfer Model

- division of the furnace layout to 7 zones: solid and liquid steel, solid and liquid slag, gas zone, roof zone, wall zone
- different phases of the melting process (electrode bore-down, exposing panels, flat bath, etc.)
- each zone possesses equal physical characteristics (i.e. temperature levels, heat capacity, heat transfer coefficients, etc.) throughout the zone



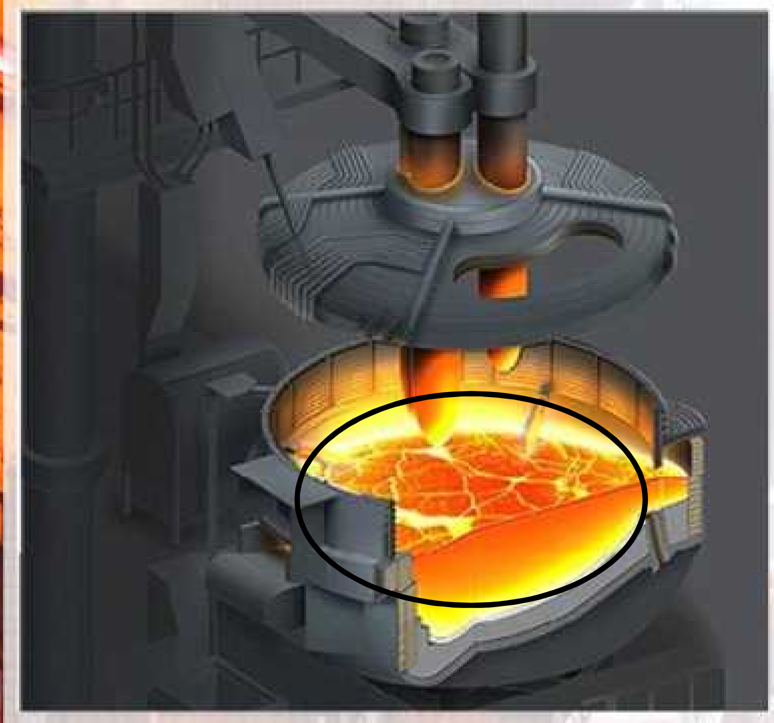
- ODEs for temperature levels based on energy input/output balances
- utilizing heat-transfers to each zone from: arcs, chemical reactions, volatile oxidation, electrode oxidation, other zones, etc.
- utilizing heat losses due to cooling of the furnace, offgas extraction, steel and slag entropy
- utilizing geometry supported (view-factor based) radiative heat exchange
- taking into the account continuous transitions between the zones (geometry supported)

EAF Process Modelling

Mass-Transfer Model

- division of the furnace layout to 5 zones: solid and liquid steel, solid and liquid slag, gas zone
- different phases of the melting process (electrode bore-down, exposing panels, flat bath, etc.)

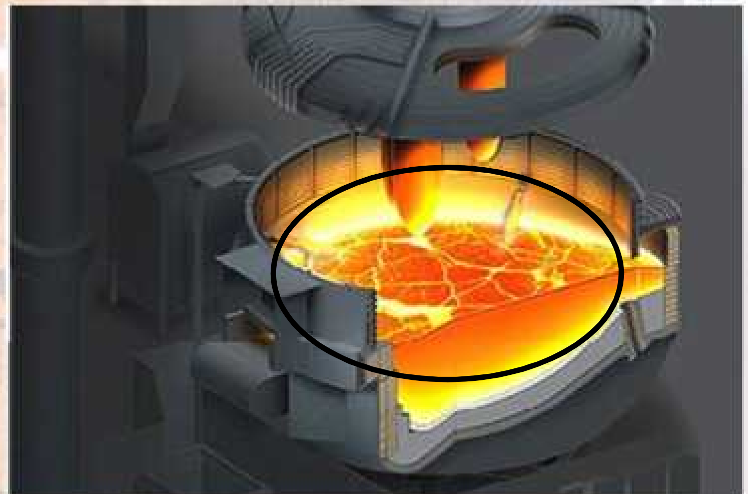
- each zone possesses equal physical characteristics (i.e. temperature, density, latent heat, etc.) throughout the zone
- elements and compounds appearing in the zones:
  - steel zone: Fe, C, Si, Cr, Mn, P
  - slag zone: FeO, SiO_2, MnO, Cr_2O_3, P_2O_5, CaO, MgO, Al_2O_3
  - gas zone: N_2, O_2, CO, CO_2
- ODEs for mass transfers based on temperature levels (melting) and energy input/output balances
- reversible dynamics (cooling and solidification)

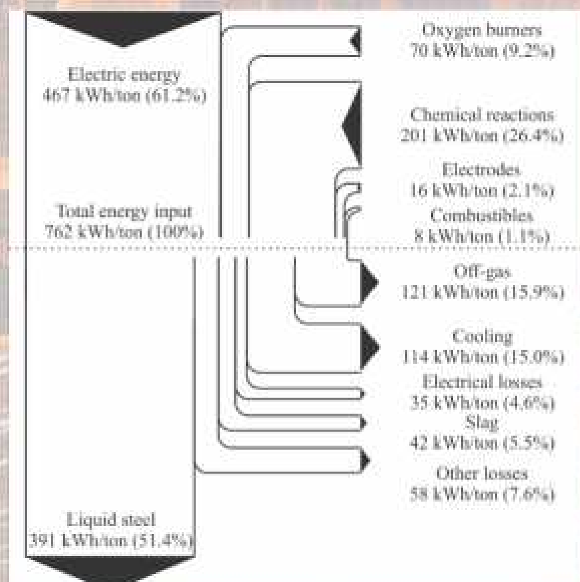


EAF Process Modelling

Chemical Model

- covering the main chemical reactions appearing in the steel-melting process:
  - oxidation of Fe, Si, Mn, C, P, CO
  - reduction of FeO, SiO_2, MnO, Cr_2O_3, P_2O_5
- ODEs for rates of change of elements/compounds based on molar equilibria with reaction equilibria constants dependent on molar composition of the zone



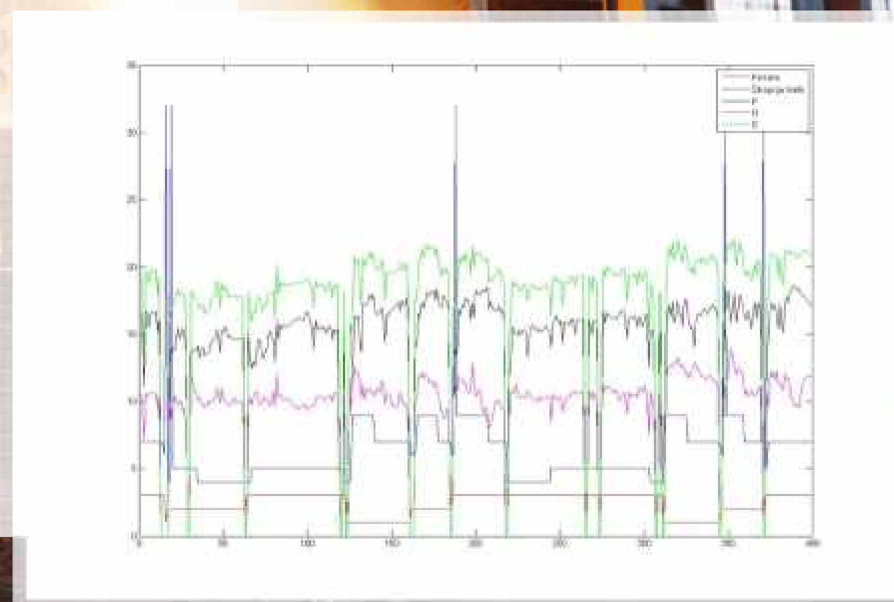


- chemical energy exchange due to:
  - exothermic reactions
  - endothermic reactions
- foaming slag height calculation based on:
  - slag density/viscosity/surface tension
  - superficial gas velocity (CO) including slag decay
- online calculation of steel, slag, gas compositions and relative pressure
- online calculation of energy balance

EAF Operational Data

Online (1s sample time)

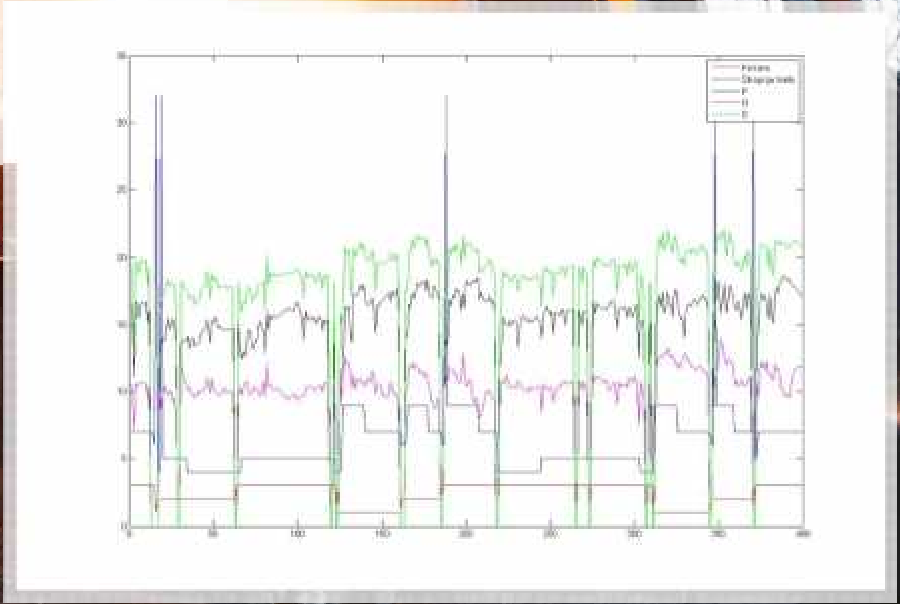
- electrical values:
  - powers: apparent, active, arc and reactive
  - voltages: secondary transformer voltage, arc voltage
  - phase currents
  - power factors
  - arc resistances, arc reactances
  - total resistances, total reactances
  - total energy consumption
- thermal values:
  - water-cooled panels temperatures
- melting program:
  - charging
  - tap selection
  - oxygen lancing, carbon injection
  - material addition, etc.



EAF Operational Data

Initial and Endpoint

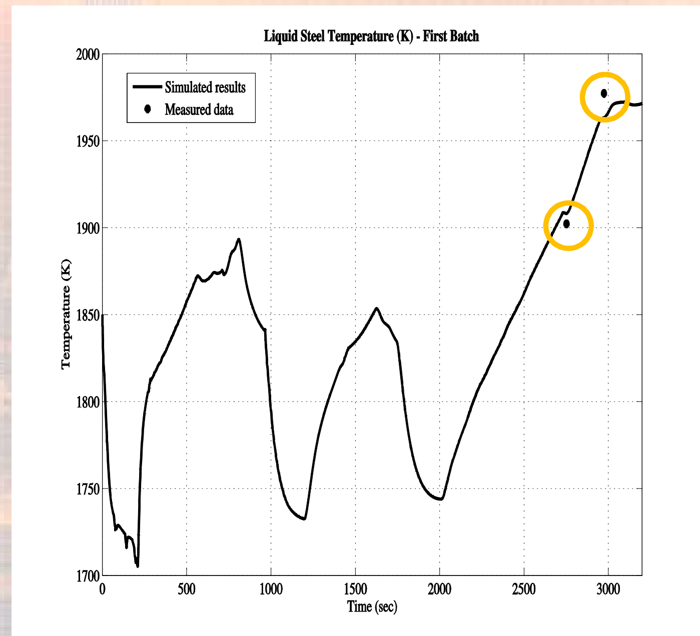
- chemical values:
  - initial and endpoint steel and slag composition
    - 1 – 3 measurements for C and O_2 before tapping
    - 1 measurement at tapping for the rest
  - consumptions (lime, dolime, C, O_2, electrical energy, ...)
- thermal values:
  - steel temperature (1 - 3 measurements before tapping)
- general:
  - power-on-time, tap-to-tap time, steel yield

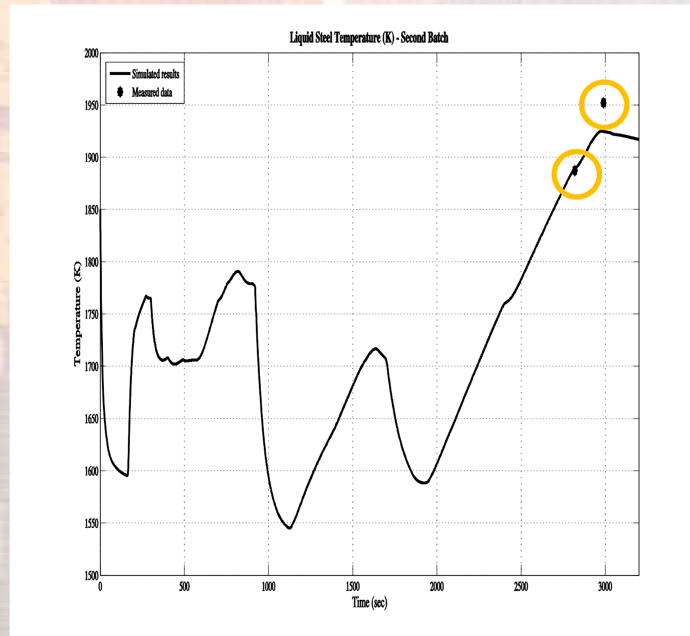


Model Validation

Validation results - single charge

- steel bath temperature at sampling





	First batch	
Time [s]	2752	2974
Measured	1902 K	1977 K
Simulated	1908 K	1963 K

	Second batch	
Time [s]	2819	2990
Measured	1887 K	1952 K
Simulated	1889 K	1925 K

Model Validation

Validation results - single charge

- steel composition at sampling

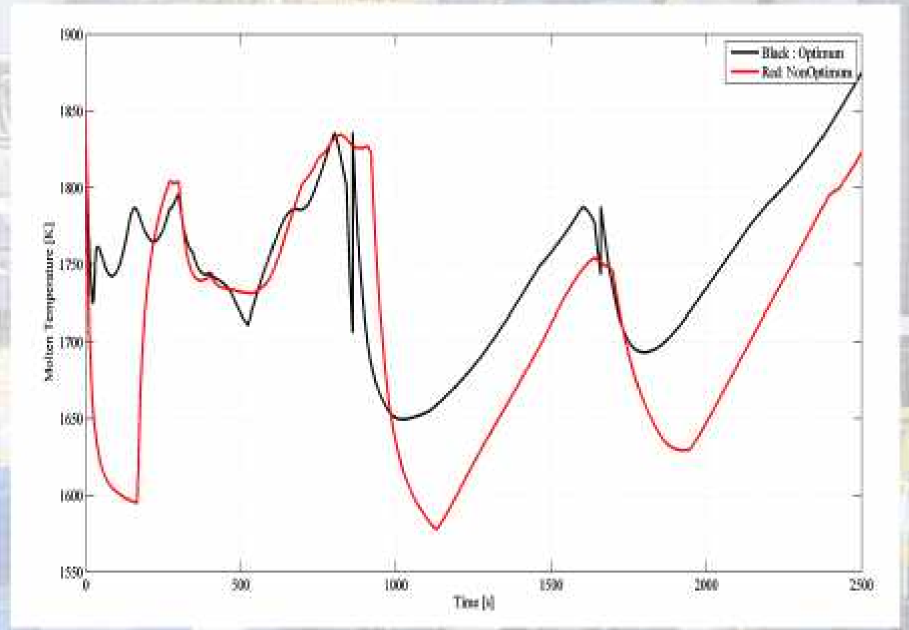
		Time [s]	[illegible] %	[illegible] %	[illegible] %	[illegible] %
First Batch	Measured	3207	0.057	0.012	0.23	0.008
	Simulated		0.056	0.011	0.21	0.009
Second Batch	Measured	2479	0.063	0.010	0.06	0.007
	Simulated		0.059	0.011	0.06	0.006
	Measured	3260	0.062	0.212	0.52	0.009
	Simulated		0.140	0.235	0.63	0.009

EAF Simulator

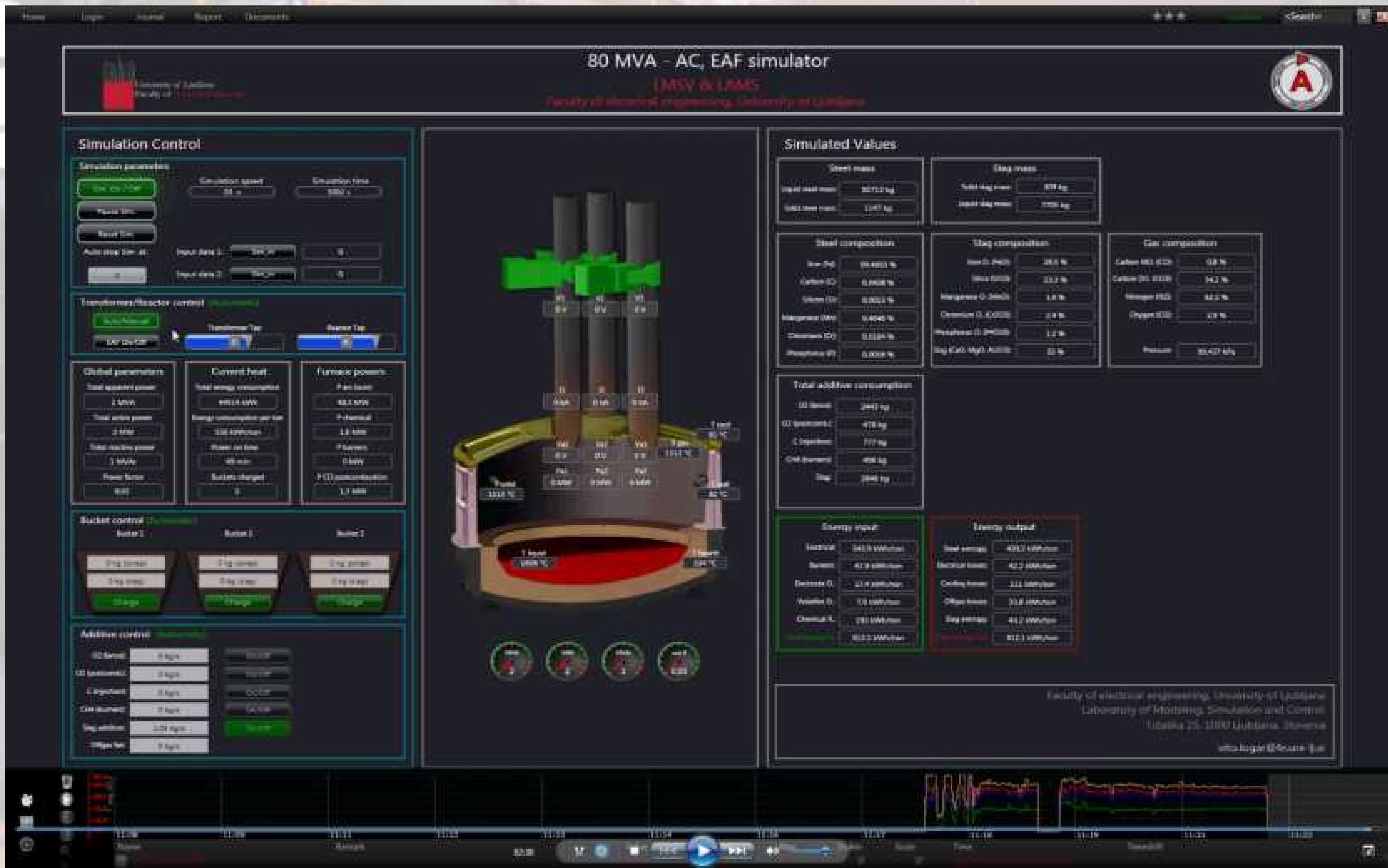
- developed in XAMControl – C# (updated and enhanced from initial Matlab sources to object-oriented programming)
- featuring extended functionality compared to Matlab (user-friendly interface, trending, archiving, etc.)
- added functionalities for graphical and numerical presentations
- currently represented in „demo“ mode, fitted to the actual EAF data
- possibility of tuning/adaptation of the process models and the simulator to any operational EAF data

Potential Use

- offline optimization of the melting programs
- offline optimization procedures (depending on data availability – simulator tuning)
- online monitoring of the process, quality of the steel bath
- online optimization – decision support
- production planning
- ...



EAF SIMULATOR



Further research

- **Offline optimization of the EAF operation**
  - **cost reduction**
  - **energy reduction**
  - **raw material use reduction**
- **Case studies on different EAF inputs**
  - **raw materials – steel types and amount, slag forming agents and amount, …**
  - **oxygen, carbon addition**
  - **other additions**
- **Research on decision support systems based on EAF models**
  - **online optimization**
  - **suggestion of the most appropriate action to the operator**
- **Model-predictive control for the EAF refining stage**
  - **automatic control of the inputs to the EAF in the last 10 – 15 minutes of operation**

Other Work

- Lecturing:
  - Regulation and control techniques (1st cycle prof. programme)
  - Automatic process control (2nd cycle post. programme)
- Exercises:
  - Modelling and simulation; Computer control of processes (1st cycle prof. programme)
  - Advanced control design methods (2nd cycle post. programme)

- Methods:
  - modelling of industrial processes, electric arc furnace processes
  - fuzzy and neuro modelling based on data, data mining
  - advanced process control, process optimization
  - e-learning (using computational tools and laboratory devices)
- Software Tools:
  - Matlab, Dymola Modelica, Siemens TIA Portal, C, C#, PHP, HTML, Javascript, CSS, ...
- Hardware:
  - pilot plants, PLCs
- Vision of the future work, cooperation, development:
  - modelling, analysis, optimization, and control design of industrial systems
  - e-learning development in technical and non-technical areas