Study of Supercritical Coal Fired Power Plant Dynamic Responses and Control for Grid Code Compliance

(EPSRC Project Ref No: EP/G062889)

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Workshop, UK-China: Partners in Energy Research

London, UK, March 2014

EPSRC Engineering and Physical Sciences Research Council

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Outline

- Background
- Overview of the project: major achievements
- Summary

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Background

Over 40% of electricity is generated from coal with CO_2 Emission of 1020kg/MWh.

Cleaner Coal Technologies

- **Improving efficiency**
  - larger scale
  - higher pressure and temperature
  - operation optimisation
  - new technologies
- **Carbon capture and storage (CCS)**

Background

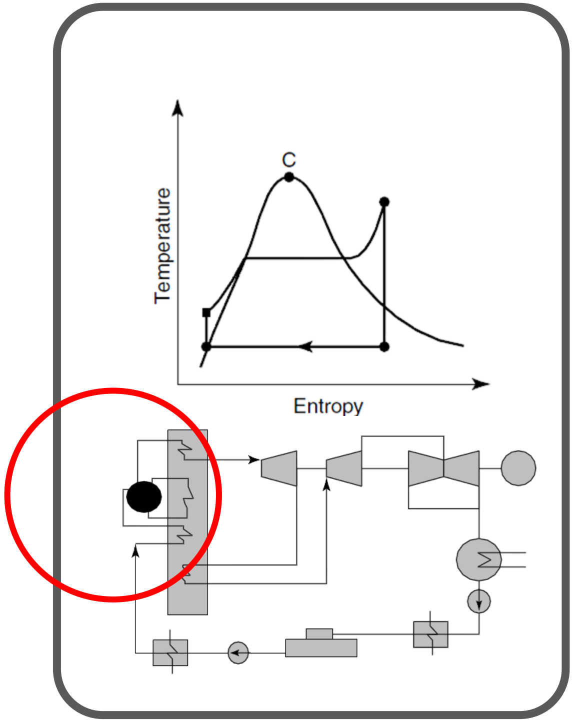
Supercritical technology

	Subcritical (conventional)	Supercritical	Ultra supercritical
Temperature (° C)	500 – 550	**500 – 600**	**550 – 600, (600 – 700)***
Pressure (MPa)	16 – 17	**24 – 26**	**27 – 32, (40 – 42)***
Features	Drum: single reheat	**Once through: single reheat**	**Once through: double reheat**
Efficiency cycle (%)	**33 - 35**	**40-45**	**42 – 47, (50 – 55)***

Background

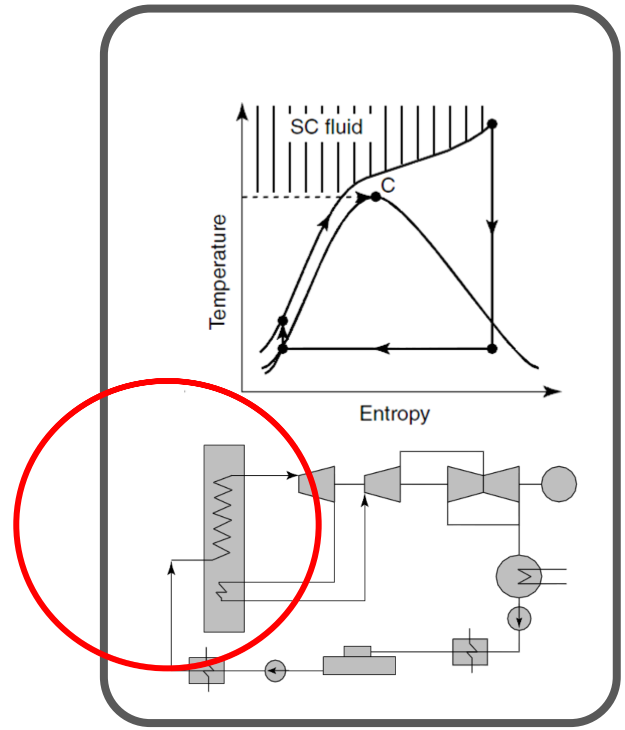
Subcritical

Subcritical water-steam cycle
Drum – energy storage



Supercritical

Supercritical water-steam cycle (no phase change)
Once-through operation – no energy storage

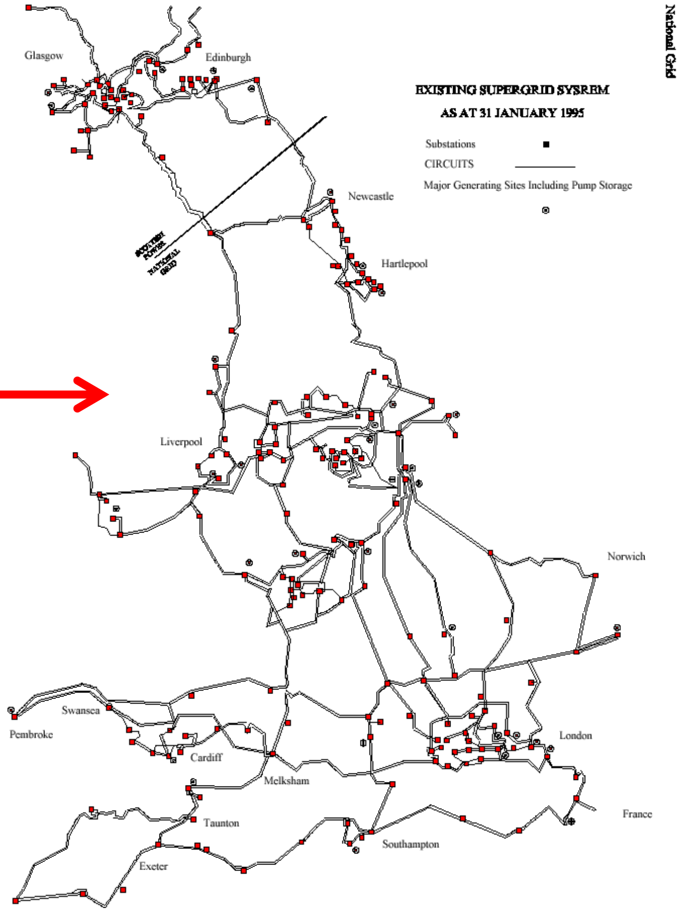


Challenges:
Can supercritical power generation responses to the demand changes fast enough to satisfy **GB Grid Code** requirement?

Background

Future new power plants in the UK - SUPERCRITICAL

? GB Grid Code



Power generation responses to the demand changes

Fast enough to satisfy the grid code specification

Background

Station Name	Representation	Company	Address				Capacity in MW
Aberthaw B	National Ash	RWE Npower	The Leys	Aberthaw, Barry	South Glamorgan	CF62 42W	1,489
Cockenzie	ScotAsh	Scottish Power	Prestopans	East Lothian			1,152
Cottam	EDF Energy	EDF Energy	Cottam Power Company, PO Box 4, nr Retford	Nottinghamshire		DN22 0ET	1,970
Didcot A	National Ash	RWE Npower	Didcot	Nr Oxford		OX11 7HA	2,020
Drax	Hargreaves CCP	Drax Power Limited	Drax	Selby	North Yorks	YO8 8PQ	3,870
Eggborough	British Energy	British Energy	Eggborough	Goole	North Humberside	DN14 0BS	1,960
Ferrybridge C	Keadby generation Ltd	Scottish & Southern Energy plc	PO Box 39, Stranglands Lane	Knottingley	West Yorkshire	WF11 8SQ	1,955
Fiddlers Ferry	Keadby generation Ltd	Scottish & Southern Energy plc	Widnes Road	Cuerdley	Warrington	WA5 2UT	1,961
Ironbridge	EON UK	PowerGen	Buildwas Road	Telford	Shropshire	TF8 7BL	970
Kingsnorth	EON UK	PowerGen	Hoo Saint Werburgh	Rochester	Kent	ME3 9NQ	1,974
Longannet	ScotAsh	Scottish Power	ScotAsh Ltd, Kincardine-on-Forth	Fife		FK10 4AA	2,304
Lynemouth	Alcan	Alcan Primary Metal - Europe	Ashington	Northumberland		NE63 9YH	420
Ratcliffe	EON UK	Powergen	Ratcliife on Soar	Nottingham		NG11 0EE	2,000
Rugeley	International Power	International Power	Rugeley Power Station	Armitage Road	Rugeley	WS15 1PR	976
Tilbury B	National Ash	RWE Npower	Fort Road	Tilbury	Essex	RM18 8UJ	1,020
West Burton	EDF Energy	EDF Energy	West Burton Power Company, Retford	Nottinghamshire		DN22 9BL	1,932
Wilton	Hargreaves CCP	ICI	PO Box 1985, Wilton International	Middlesborough		TS90 8WS	100

List of UK power stations - All Subcritical (~33% efficiency)

Overview of the project

Objectives:

Through study supercritical coal fired power plant mathematical modelling and simulation:

- to understand the dynamic responses of supercritical power plants and GB Grid Code Compliance
- to investigate the possible strategies for improvement

Strategy:

Collaboration with the researchers in China

Overview of the project

THE UNIVERSITY OF WARWICK

Mathematical modelling, simulation study, dynamic response analysis, optimal control, Grid Code studies

UNIVERSITY OF BIRMINGHAM

Supercritical water, test rig development, Experimental studies, data collection and analysis

Consortium interactions

- Exchange of materials, data, information
- Shared models, software and simulations
- Integrated testing programme

清華大學 Tsinghua University

Industrial scale power plant modelling and simulation, software development, verification

华北电力大学 North China Electric Power University

Power plant control, intelligent algorithms,

Industrial partners: e·on, EMERSON, SCOTTISHPOWER, EPRI

Overview of the project

Team:

Warwick: **Professor Jihong Wang**
Dr Jacek D Wojcik
Mr Mihai Draganescu
Mr Shen Guo,
Mr (Dr) Omar Mohamed (graduated)

Birmingham: **Dr Bushra Al-Duri**
Dr Iain Kings
Mr Sam Massoudi
Mr Alvaro Gil

Tsinghua University: **Professor Junfu Lv**
Professor Qirui Gao
Dr Yali Xue

North China Electric Power University: **Professor Xiangjie Liu**
Professor Guolian Hou

Major achievement 1 – Grid Code study

Frequency Variation Interval [Hz]		
Country	**Normal Operation**	**Critical Situations**
UK	**49.5 – 50.5**	**47.0 – 52.0**
Northern Ireland	49.5 – 50.5	47.0 – 52.0
Ireland	49.8 – 50.2	47.0 – 52.0
France	49.5 – 50.5	47.0 – 52.0
Italy	49.9 – 50.1	47.5 – 51.5
Italy (Sicily & Sardinia)	49.5 – 50.5	47.5 – 51.5
Austria	49.5 – 50.5	47.5 – 51.5
Romania	49.5 – 50.5	47.0 – 52.0
Poland	49.5 – 50.5	47.0 – 52.0
Australia	49.75 – 50.25	47.0 – 52.0
Australia (Tasmania)	49.75 – 50.25	47.0 – 55.0
China	49.8 – 50.2	48.0 – 51.0

Frequency Control Strategies			
Country	**Type of Frequency Control Strategy**		**Response Time**
Northern Ireland & Ireland	Operating Reserve	Primary Operating Reserve	active power increase within ***5 s*** and maintained for another ***15 s***
		Secondary Operating Reserve	active power increase within **15 s** and maintained for another **90 s**
		Tertiary Operating Reserve band 1	active power increase within **90 s** and maintained for another **5 min**
		Tertiary Operating Reserve band 2	active power increase within **5 min** and maintained for another **20 min**
France, Italy, Austria, Romania, Poland (UCTE members)	Primary Control		• 50% of the active power increase within ***15 s***; • 100% of the active power increase within ***30 s***; • 100% of the active power increase supplied for at least ***15 min***. *The quantum of active power required for Primary Control is regulated by the Transmission System Operator, for each Generating Unit apart.*
	Secondary Control		activated no later than **30 s** after the incident and its operation must end within **15 min** at the latest
	Tertiary Control		activated during Secondary Control and maintained for no longer than **15 min**.

UK Frequency Control Strategies	
Frequency Control Strategy	**Response Time**
Primary Frequency Response	active power increase within **10 s** and maintained for another **30 s**
Secondary Frequency Response	active power increase within **30 s** and maintained for another **30 min**
High Frequency Response	active power decrease within ***10 s*** and maintained ***thereafter***

Frequency Control Strategies		
Country	**Type of Frequency Control Strategy**	**Response Time**
Australia	Fast Raise Service, Fast Lower Service	active power increase within ***6 s,*** active power decrease within ***6 s***
	Slow Raise Service, Slow Lower Service	active power increase within ***60 s.*** active power decrease within ***60 s***
	Delayed Raise Service, Delayed Lower Service	active power increase within ***5 min.*** active power decrease within ***5 min.***
	Regulating Raise Service	active power increase needed for ***5 min.*** dispatch interval
	Regulating Lower Service	active power decrease needed for ***5 min.*** dispatch interval
China	Primary Frequency Control	active power increase within ***15 s***
	Secondary Frequency Control	N/A

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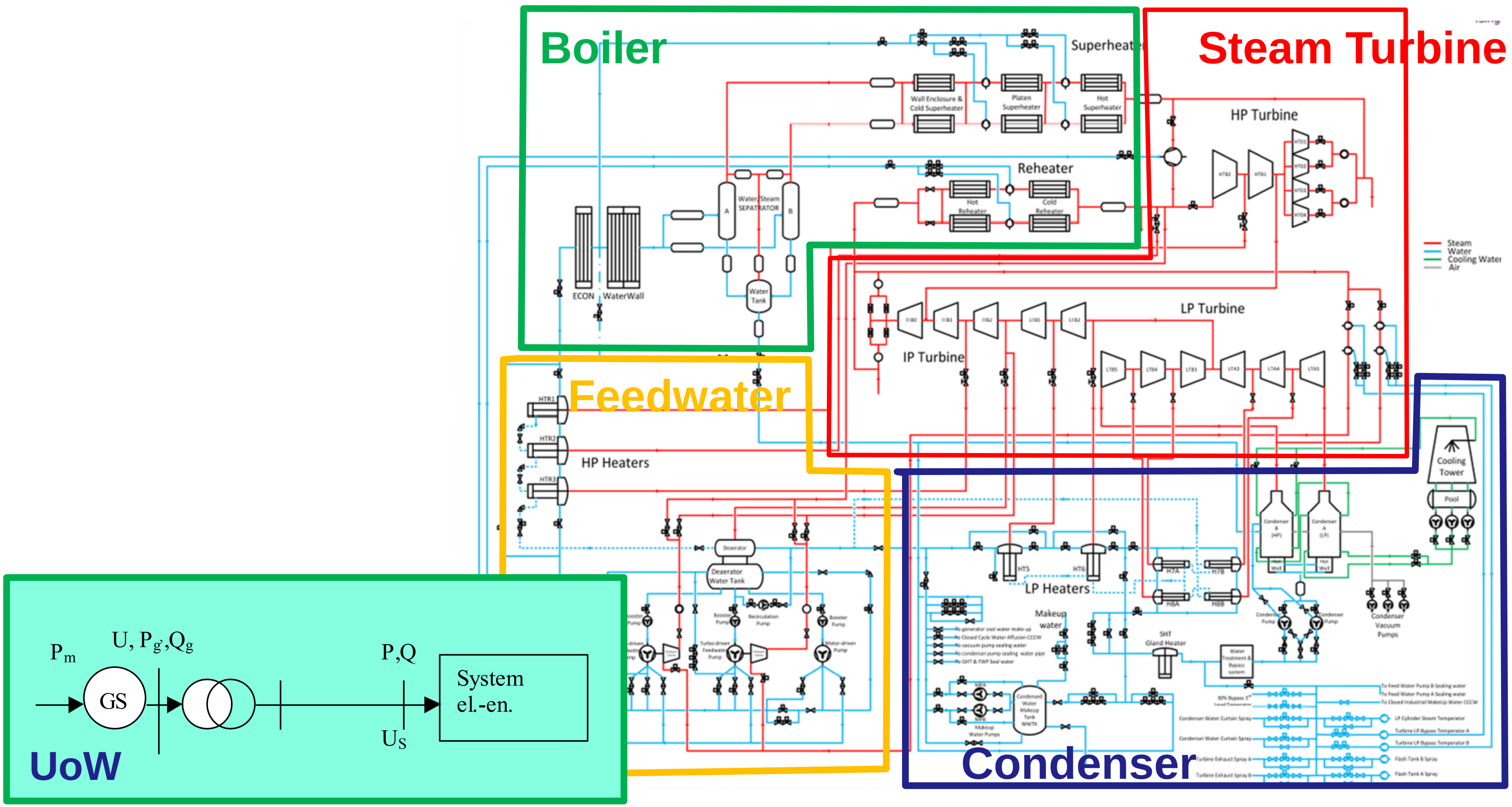
Major achievement 2 – Mathematical modelling and simulation

SCPP Water-Steam Loop (TU & UoW)



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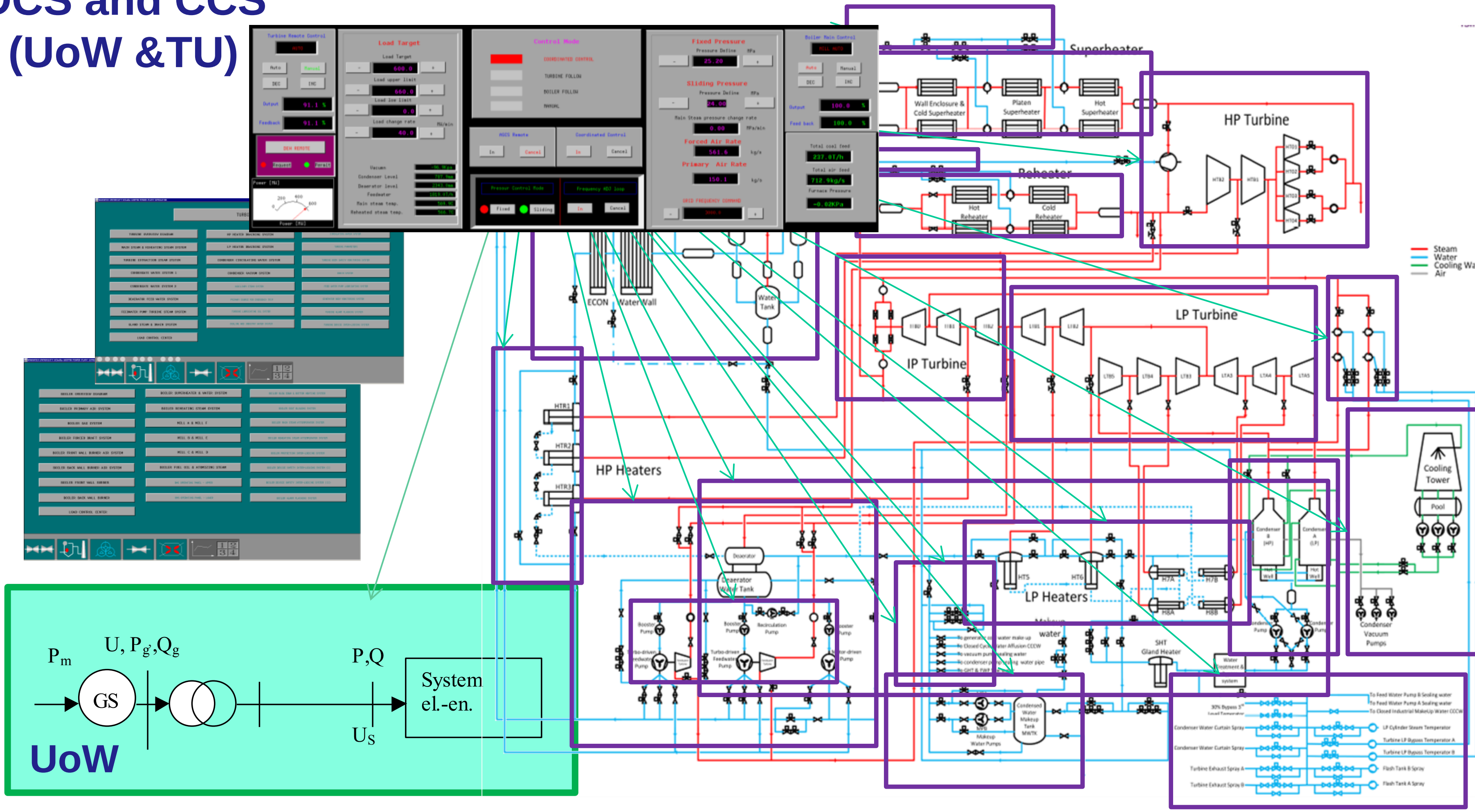
Major achievement 2 – Mathematical modelling and simulation

DCS and CCS (UoW &TU)

SCPP Water-Steam Loop (TU)



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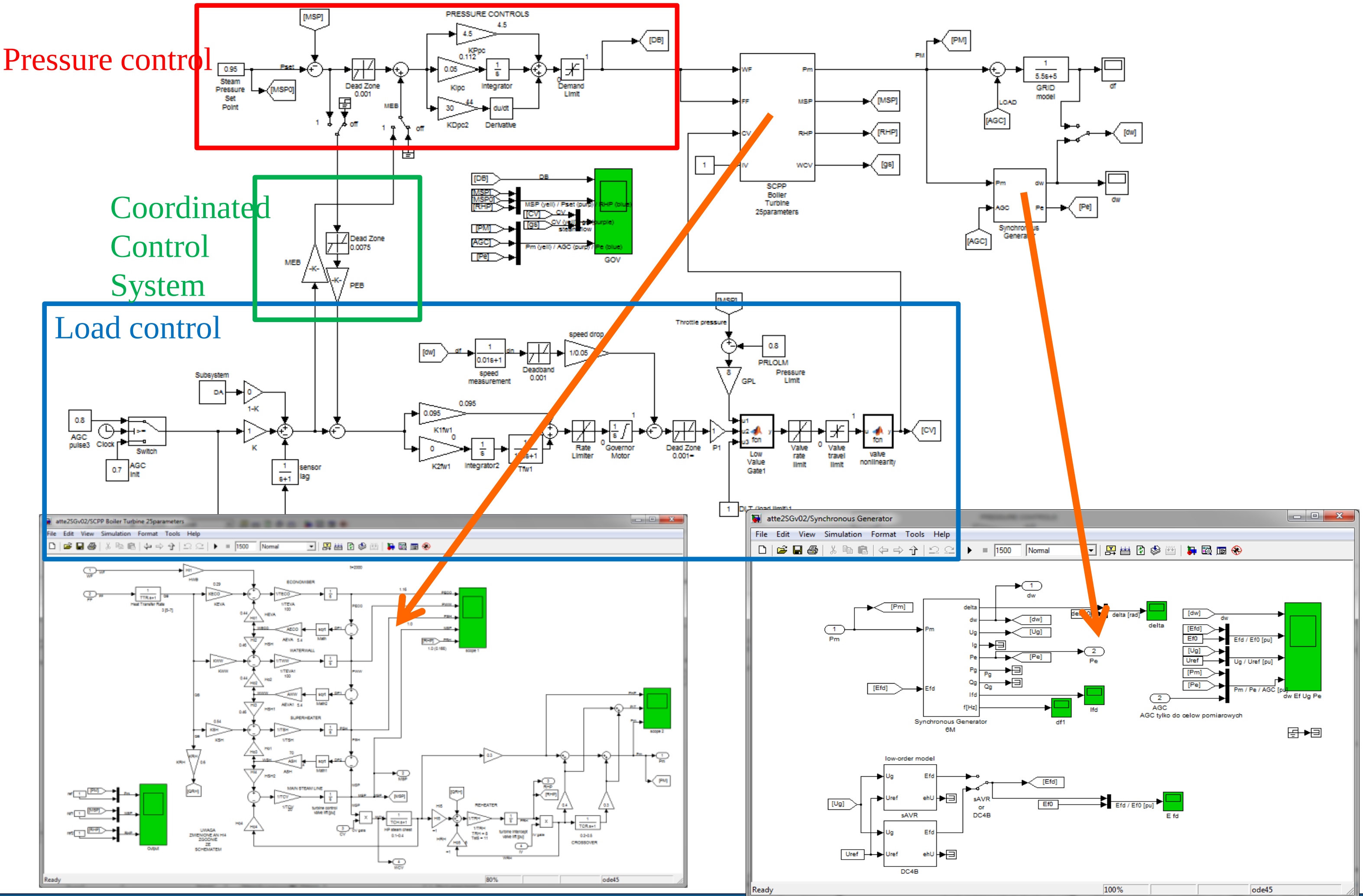
Major achievement 2 – Mathematical modelling and simulation

Simplified SCPP Simulink model (UoW)



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Tsinghua University

North China Electric Power University

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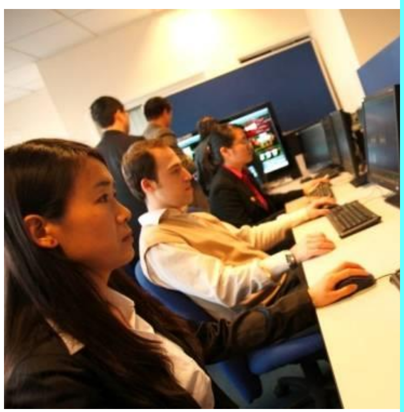
Major achievement 2 – Mathematical modelling and simulation

A joint Research Lab is set up at Warwick in May 2012



- SimuEngine 2000 (TU&UoW)
- UoW Simulink/Matlab model
- ThermoLib
- gPROMS
- ProTrax
- ANSYS package

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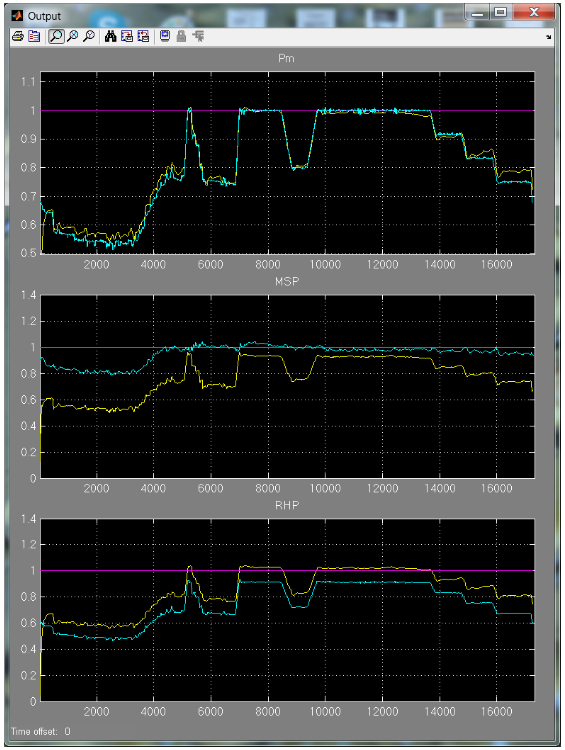
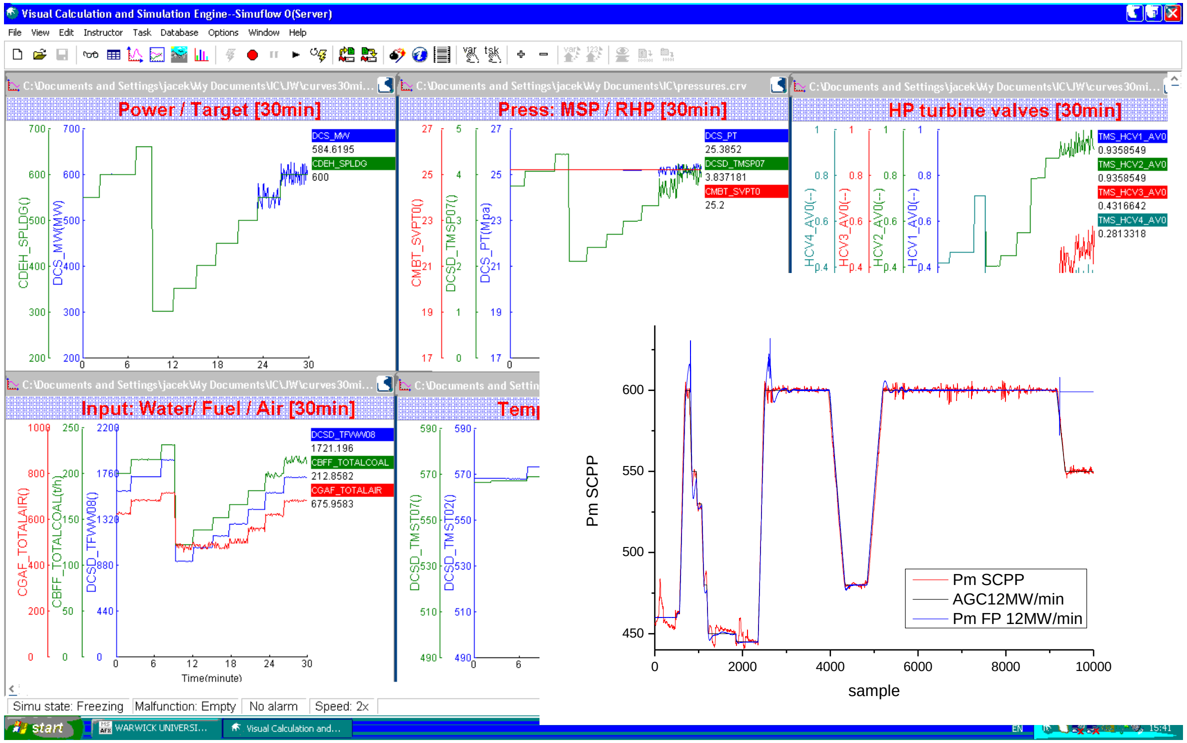
Major achievement 3 – Model validation and improvement

- on-site plant measurement data ← Chinese partners
- joint efforts of all the four academic institutes





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华北电力大学 North China Electric Power University
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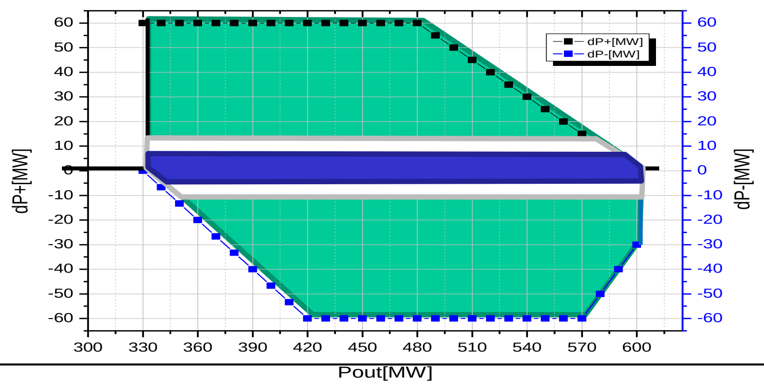
Major achievement 4 – UK Grid Code compliance study

LOADING UP

Load [%]	SIMUENGIN ETime [s]	MATLAB Time [s]
70+10%	140	107.5
75+10%	137	131.75
80+10%	**148**	**149.5**
85+7.66%	**152**	**154.05**
90+5%	**149**	**156**
95+3.33%	175	159.5
100	-	-

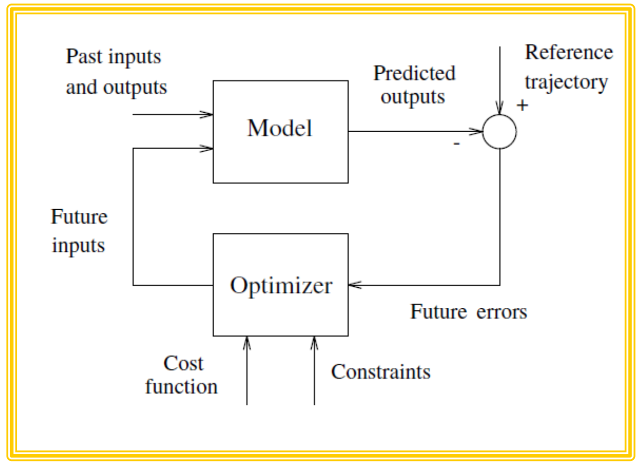
LOADING DOWN

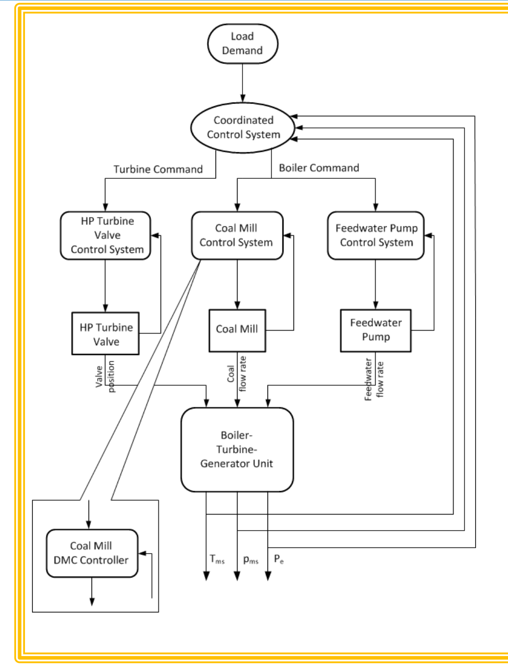
Load [%]	SIMUENGINE Time [s]	MATLAB Time [s]
70-10%	123	95.5
75-10%	125	96.35
80-10%	129	96.9
85-10%	136	104.5
90-10%	141	122
95-10%	**142**	**148.5**
100-5%	168	150

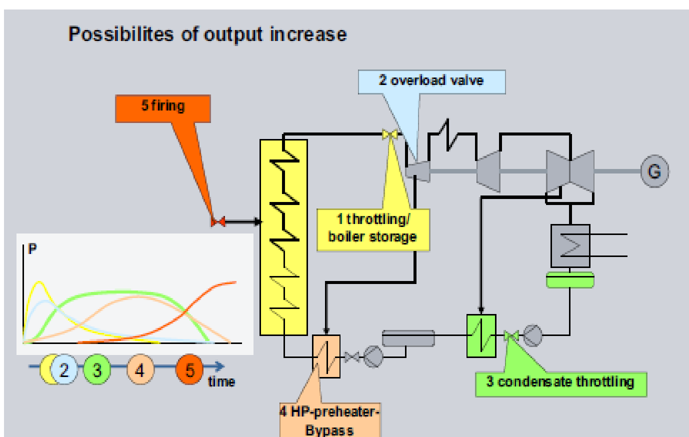


Major achievement 5 – New control strategy study

Model Predictive Control for plant milling process (UoW, TU, NCEPU)







How to improve PP dynamic response?

Condensate stop is very popular solution in China (Siemens technology)

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Publications

List of Journal Papers:

- Draganescu, M., Guo, S., Wojcik, J., Wang, J., Xue, YL, Gao, QR., Liu, XJ, Hou, GL., Dynamic matrix model predictive control of the mill coal flow rate for improving dynamic performance of a supercritical coal fired power plant, accepted for publication by *International Journal of Automation and Computing*, 2013, to appear 2014.
- Guo, S., Wang, J., Wei, J.L., Zachriasdes, P., A new model-based approach for power plant Tube-ball mill condition monitoring and fault detection, *Energy Conversion and Management*, (80), pp10-19, 2014.
- Liu, X.J., Kong, X.B., Hou, G.L., Wang, J., Modelling of a 1000MW power plant ultra super-critical boiler system using Fuzzy-Neural network methods, *Energy Conversion and Management*, Vol 65, pp518-527, 2013.
- Sun, Z.X., Wang, J.F., Dai, Y.P. and Wang, J., Exergy analysis and optimization of a hydrogen production process by a solar-liquefied natural gas hybrid driven transcritical CO_2 power cycle, International Journal of Hydrogen Energy, Vol.37,No.24. pp18731-18739, Dec 2012.
- Mohamed, O.I., Wang, J., Al-Duri, B., Lu, J.F., Gao, Q.R., Xue, Y.L., Study of a multivariable coordinate control for a supercritical power plant process, *International Journal of Energy Engineering*, Vol 2, No. 5, pp210-217, 2012.
- Mohamed, O., Wang, J., Guo, S., Wei, J.L., Al-Duri, B., Lv, J. and Gao, Q., Mathematical modelling for coal fired supercritical power plants and model parameter identification using genetic algorithms, a book chapter in *Electrical Engineering and Applied Computing*, Springer, 2011.

List of Conference Papers

- Draganescu, M., Wang, J., Wojcik, J., Guo, S., Dynamic matrix control of coal feeder speed of a supercritical power plant, the proceedings of ICAC 2013, London, UK, Sept. 2013.
- Mohamed, O., Wang, J., Al-Duri, B., Lu, J.F., Gao, Q.R., Xue, Y.L., Liu, X.J., Predictive Control of Coal Mills for Improving Supercritical Power Generation Process Dynamic Responses, *the Proceedings of the 51st IEEE CDC Conference*, Hawaii, USA, Dec. 2012.
- Sun, Z.X., Dai, Y.P., Liu, H., Wang, Y. and Wang, J., Dynamic performance of a dual-pressure waste heat recovery system under partial load operation, *the 19th International Conference of Computing and Automation*, Loughborough, UK, Sept 2012.
- Xue, Y.L., Li, D.H., Zhang, Y.Q., Gao, Q.R., Wang, J. and Sun, Z.X., Decentralized Nonlinear Control of 300MWe Circulating Fluidized Boiler Power Unit, *UKACC International Conference in Control*, Cardiff, UK, Sept 2012.
- Mohamed, O., Al-Duri, B., Wang, J., Predictive Control Strategy for a Supercritical Power Plant and Study of Influences of Coal Mills Control on its Dynamic Responses, *UKACC International Conference in Control*, Cardiff, UK, Sept 2012.
- Liu, X.J., Hou, G.L., Wang, J., The dynamic Neural network modelling of a Ultra Supercritical Boiler unit, accepted by *IEEE American Control Conference*, San Francisco, USA, 29th June-1st July, 2011.
- Mohamed, O., Wang, J., Guo, S., Al-Duri, B., Wei, J.L., Modelling Study Of Supercritical Power Plant And Parameter Identification Using Genetic Algorithms, *The proceedings of World Congress of Engineering*, Vol II, London, UK, pp973-978, July 2010. ISBN: 978-988-18210-7-2, ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Interactions

- Joint UK-China Workshop/kick-off meeting in the UK in Dec 2009
- Joint ***EPSRC Project Progress Meeting/Workshop*** in Oct 2011 at the University of Nottingham, UK
- Organised an international ***Workshop on Modelling and Simulation of Power Plant and CCS Process***, 20-21 March 2012 at the University of Warwick, UK

- Profs Gao and Xue visited Warwick for three months and worked on setting up the simulation software, Feb-May, 2012.

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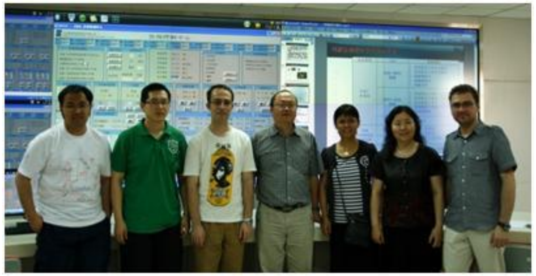
Interactions

✓***Thermal Power Plant Modelling and Simulation Laboratory*** opened on 3rd May 2012 at the University of Warwick, UK

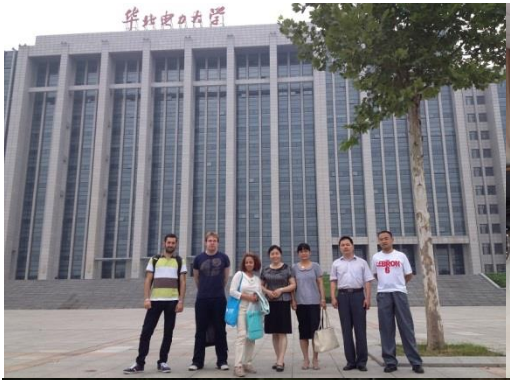
✓ **Project Progress Meeting/Workshop** in Beijing, China (July 2012)



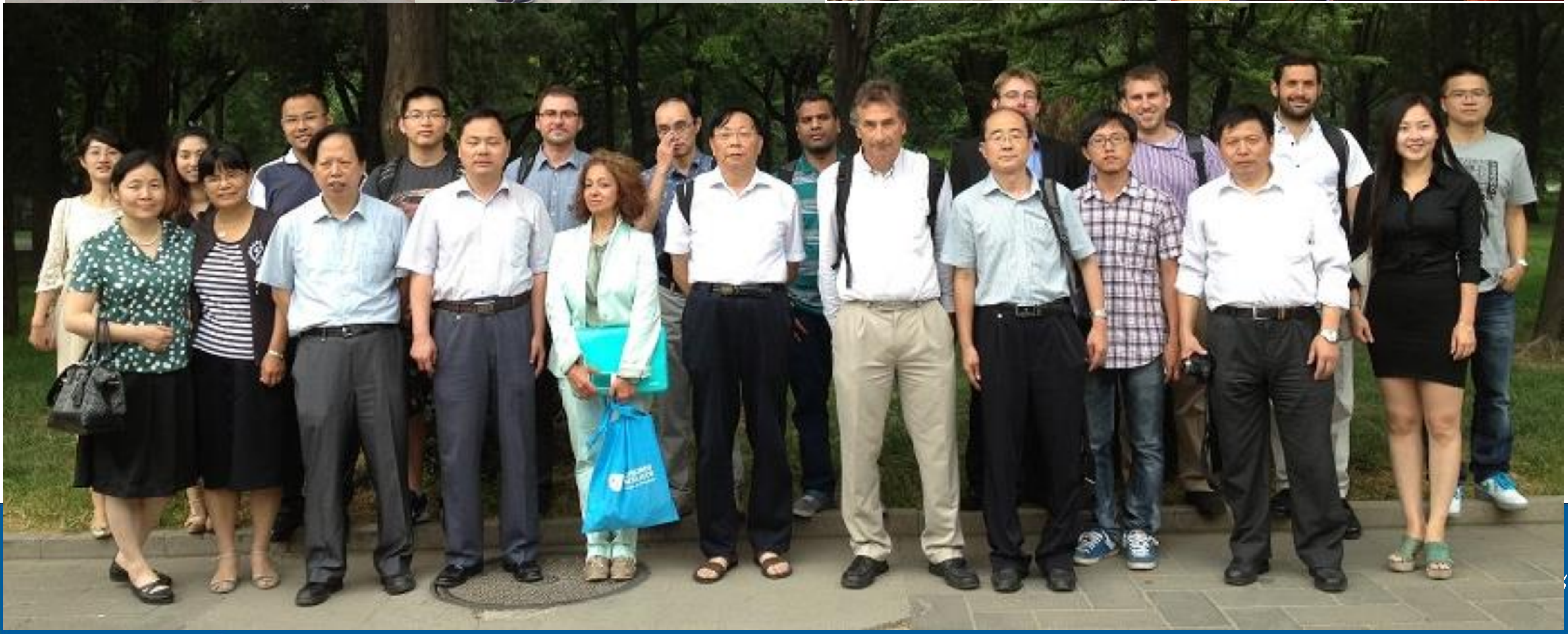



Interactions

✓ **Joint Project Progress Meeting/Workshop** in Beijing, China (Aug 2013)







Summary

- Without the collaboration between UK and China, it is impossible to conduct the project work.
- The major project objectives are achieved.
- The supercritical power plant simulation software platform provides a unique research facility for UK academic institutes. This facility is now used for
    - study of post combustion carbon capture dynamic process
    -

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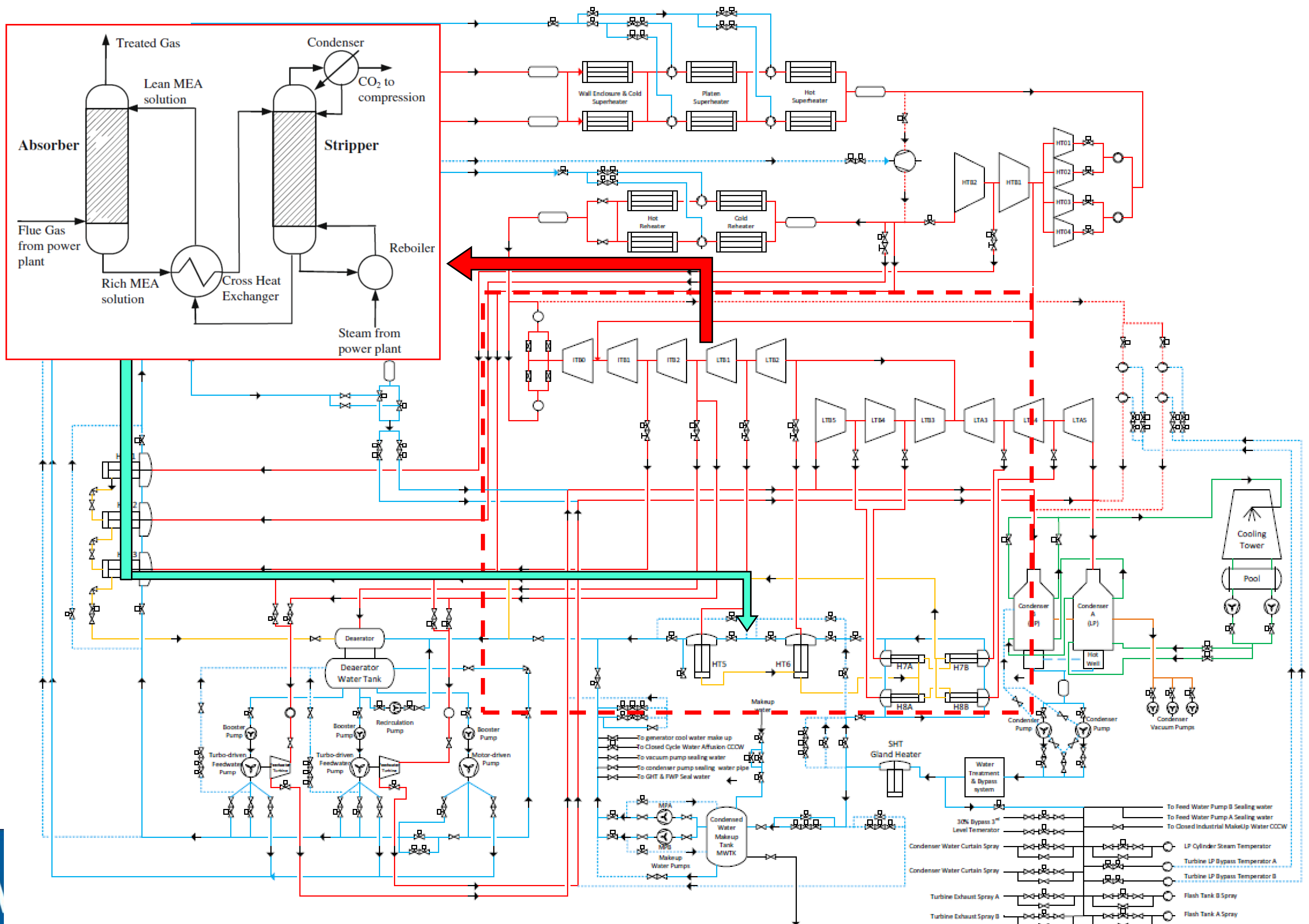
Summary

Supercritical Thermal Power Plant – Steam-Water Loop



SR Lab

Summary

- Without the collaboration between UK and China, it is impossible to conduct the project work.
- The major project objectives are achieved.
- The supercritical power plant simulation software platform provides a unique research facility for UK academic institutes. This facility is now used for
  - study of post combustion carbon capture dynamic process
  - supporting the research in grid scale energy storage: study of high temperature thermal storage
  - supporting the future research plan in using the thermal power plant thermal inertia as energy storage for load balancing and peak shaving.
  - teaching
- **Most important: long-term collaboration between all the partners**

Thank you!