PRECOMBUSTION CAPTURE PLANTS

IGCC WITH CCS, DESIGNS AND EXPERIENCE

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Workshop on Operating Flexibility of Power Plants with CCS - London 12th November 2009

AGENDA

- Configuration of an IGCC plant with CO_2 capture
- Issues related to the plant operation
  - Performance
  - Availability/Reliability
  - Flexibility
  - Electrical Requirements (grid prescriptions)
- How does the design help to meet the operating targets?
- The design tools to be applied in addition to the steady state simulations:
  - RAM (Reliability/Availability/Maintenability Analysis)
  - Dynamic Simulation
  - Electrical Studies
- Some case studies from Foster Wheeler references

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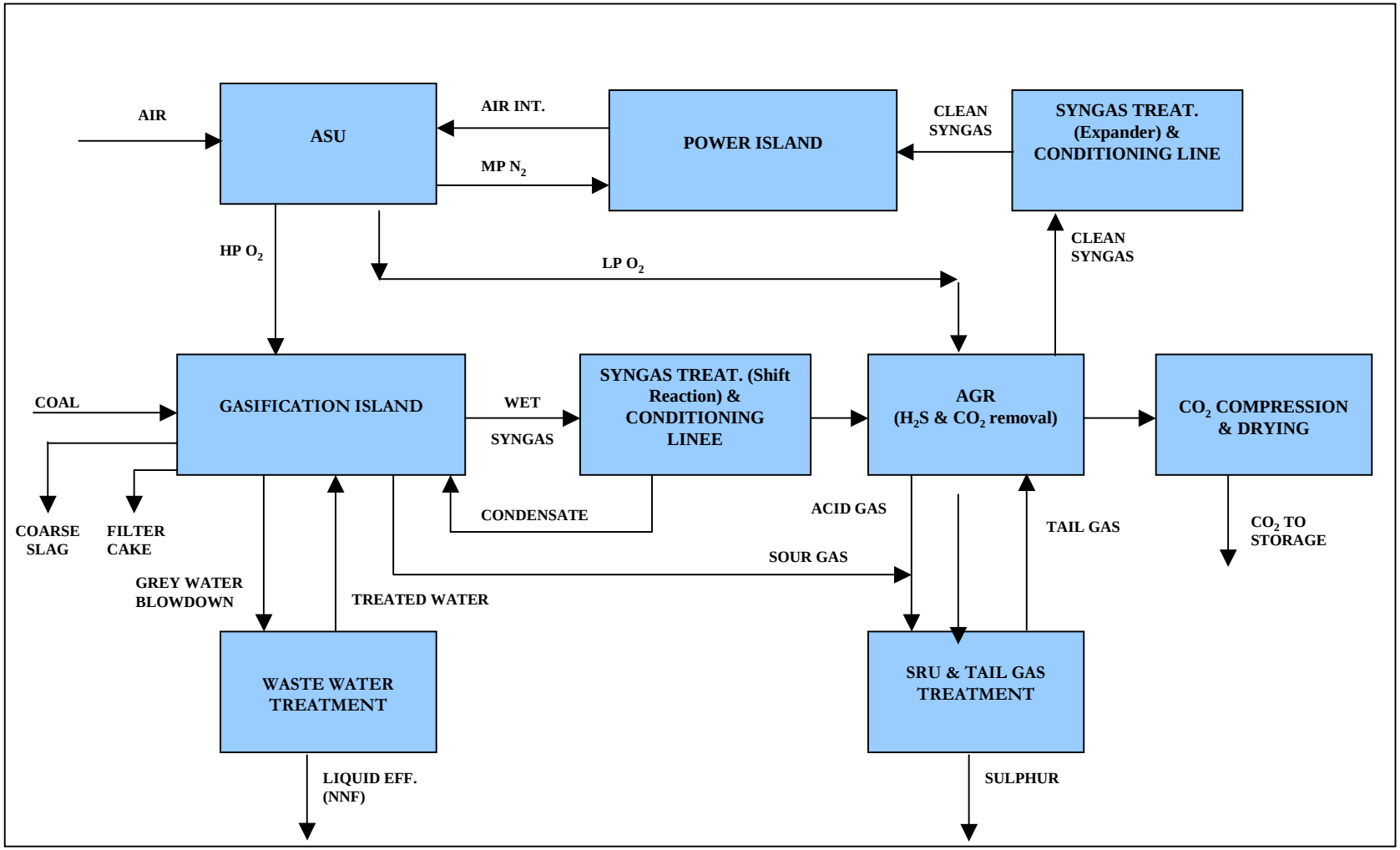
Configuration of an IGCC with CO_2 capture



MORE THAN 20 UNITS THAT SHALL OPERATE AS A SINGLE ONE

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Issues related to the plant operation

- Performance
- Availability/Reliability → Investment Cost
- Operating flexibility and grid prescriptions

A larger integration improves the plant performance and the investment cost, but can reduce the operating flexibility and the reliability

THE DESIGN SHALL FOCUS ON THE RECONCILIATION OF THE ABOVE TARGETS

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Design Guidelines

- Adoption of commercially proven technologies & equipment
- Partial Integration only (no full integration) between the gas turbine and the ASU: to be evaluated case by case
- Optimization of heat recovery
- Adoption of sparing and split into two lines just in the critical areas and if justified by the RAM calculations
- Development of a robust control philosophy – suitable control logics to handle all the emergency situations

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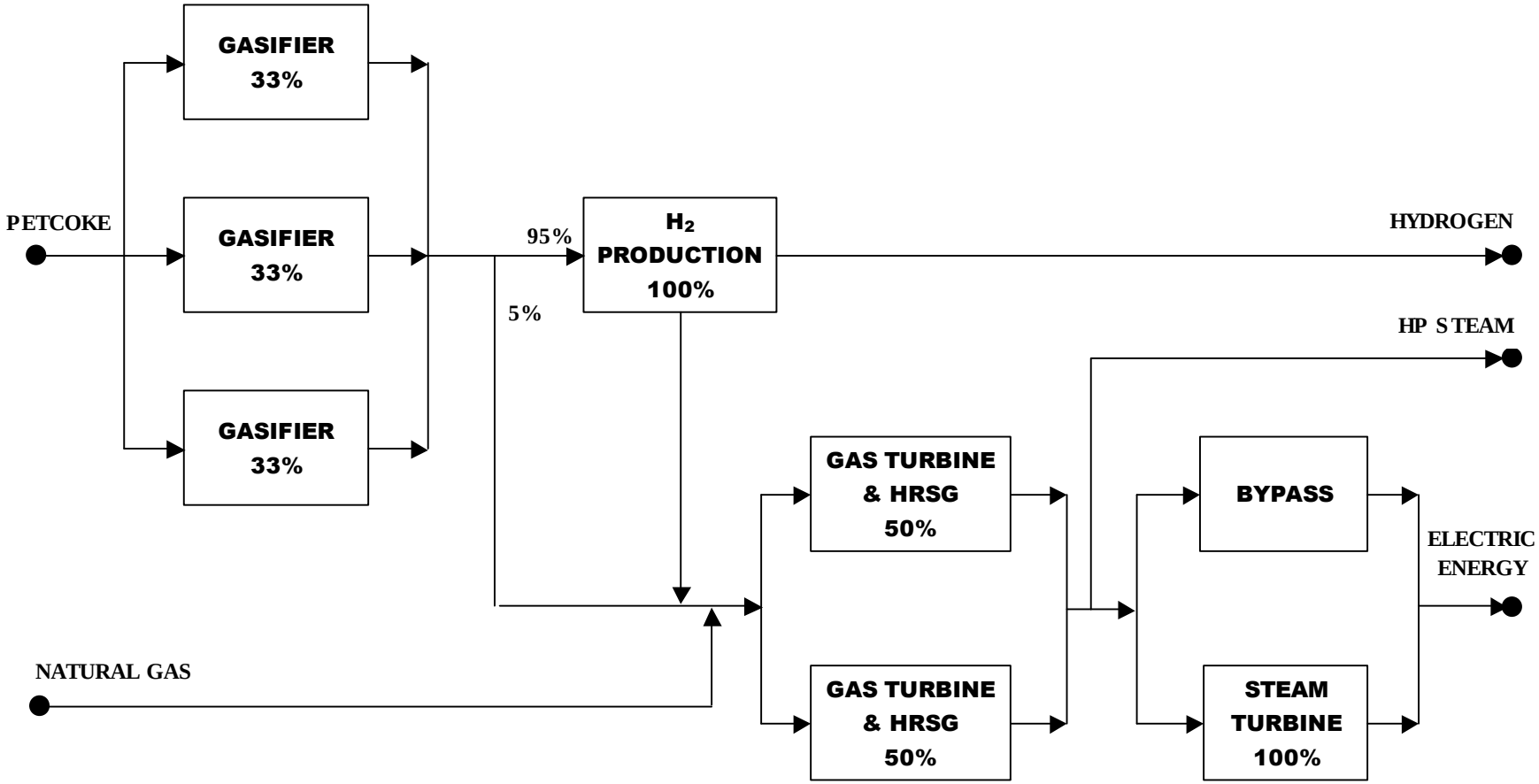
The Design Tools: RAM Analysis

A Case Study: Availability Block Diagram



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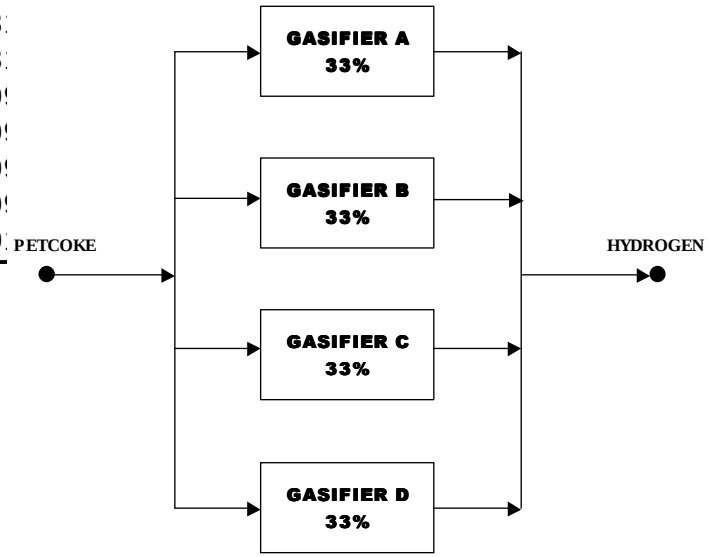
The Design Tools: RAM Analysis

IGCC availability assessment methodology – states definition

STATE	A Gasifier 1	B Gasifier 2	C Gasifier 3	D Gasifier 4	Capacity	Probability	A Gasifier 1	B Gasifier 2	C Gasifier 3	D Gasifier 4
1	1	1	1	1	100.00%	65.61%	90.00%	90.00%	90.00%	90.00%
2	1	1	1	0	100.00%	7.29%	90.00%	90.00%	90.00%	10.00%
3	1	1	0	1	100.00%	7.29%	90.00%	90.00%	10.00%	90.00%
4	1	0	1	1	100.00%	7.29%	90.00%	10.00%	90.00%	90.00%
5	0	1	1	1	100.00%	7.29%	10.00%	90.00%	90.00%	90.00%
6	1	1	0	0	66.66%	0.81%	90.00%	90.00%	10.00%	10.00%
7	1	0	1	0	66.66%	0.81%	90.00%	10.00%	90.00%	10.00%
8	0	1	1	0	66.66%	0.81%	10.00%	90.00%	90.00%	10.00%
9	0	0	1	1	66.66%	0.81%	10.00%	10.00%	90.00%	90.00%
10	1	0	0	1	66.66%	0.8				
11	0	1	0	1	66.66%	0.8				
12	1	0	0	0	33.33%	0.0				
13	0	1	0	0	33.33%	0.0				
14	0	0	1	0	33.33%	0.0				
15	0	0	0	1	33.33%	0.0				
16	0	0	0	0	0.00%	0.0				



Example: 4 x 33% Gasifiers

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The Design Tools: RAM Analysis

IGCC availability assessment methodology – states definition

Example: 4 x 33% Gasifiers

Capacity levels and probabilities

STATE	Probability (Pk) (%)	Duration (hours/year)	Capacity (Ck) (%)
I	94.77%	8301.9	100.00%
II	4.86%	425.7	66.66%
III	0.36%	31.5	33.33%
IV	0.01%	0.9	0.00%
Total	**100.00%**	**8760.0**	-

Equivalent Availability: ratio between actual syngas produced during a year and the syngas which could be produced during the year if operating all time at full capacity

EA = 100% - (100%-66.66%)x4.86% - (100%-33.33%)x0.36% - (100%-0%)x0.01% = **98.10%**

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The Design Tools: Dynamic Simulation

The main target of the IGCC dynamic symulation is:

Check of the integration between the gasification section and the combined cycle which shall ensure at any time the balance between the fuel demand and the fuel production

Response time is very quick for the gas turbine, much slower for the process units and the steam cycle

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The Design Tools: Dynamic Simulation

Dynamic Model Preparation

- Data gathering: PFDs, H&MBs at different operating conditions, equipment functional and geometrical data, control valves and controllers data, plant operating philosophy and control logics
- Model preparation: Build a dynamic model describing the sections of the plant which are dynamically significant. Generation of a model schematic and definition of modules (from std software library or developed ad hoc) and connections, implementation of control strategy. All the main components (gasifiers, scrubbers, exchangers, drums, absorbers, expander, combustors, gas and steam turbines, HRSGs, etc.) are modeled as a series of resistence and volume modules connected in a thermal/hydraulic network
- Superimpose a H&MB without any disturbance and check that no drift from steady state conditions occurs. The same is made for other operating cases to check the model vs the design and offdesign operating conditions
- Impose a disturbance and predict the consequent transient behaviour of the plant before meeting a new a steady state condition

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The Design Tools: Dynamic Simulation

Evaluation of Plant Transients

- Planned events: gasification and combined cycle load variations
- Unplanned events:
  - Trip of one gasifier
  - Trip of two gasifiers
  - Trip of other process key equipment (f.i. saturator, expander)
  - Trip of one gas turbine
  - Load rejection of one gas turbine
  - Trip of one steam turbine
  - Sudden disconnection from the electric grid and island operation
  - Requests from TSO

The System's response in terms of flow, pressure, temperature, power output are observed and discussed

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The Design Tools: Dynamic Simulation

The dynamic simulation can be performed at various stages of the project with different level of details, targets and consequent results

Some examples

- Pre-FEED: screening of different alternatives, preliminary definition of the control strategy and operating parameters
- FEED: check of equipment size, definition of control philosophy and preliminary selection of safe operating procedure
- EPC: Final check of equipment size, check of all the control logics, estimate of the controllers parameters for a shorter and less expensive tuning on field
- Plant operation: improvement of the plant operability/reliability

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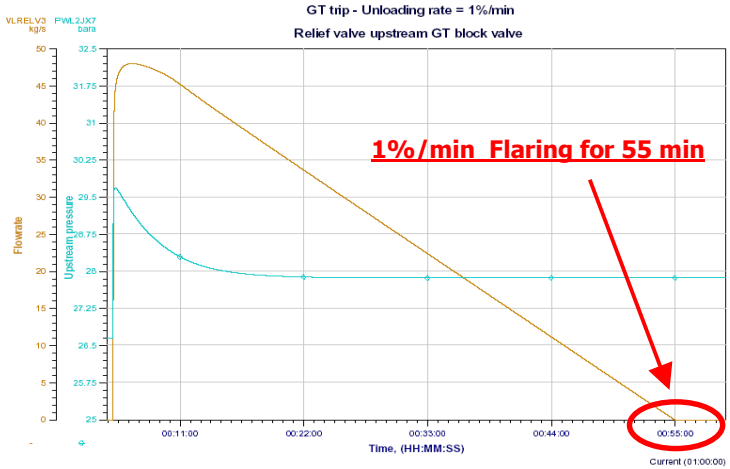
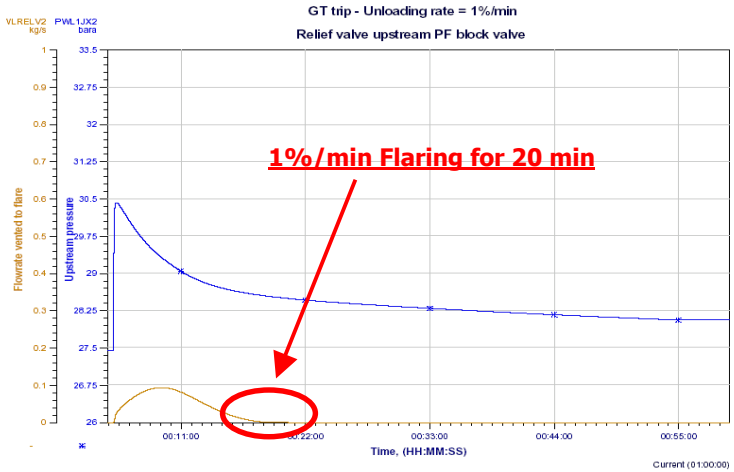
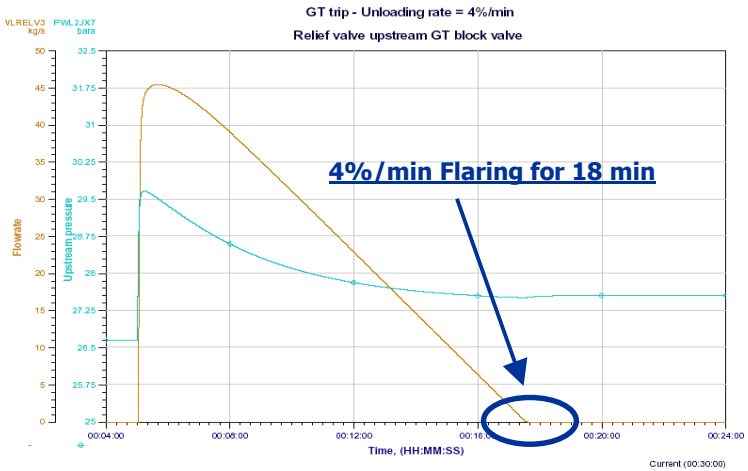
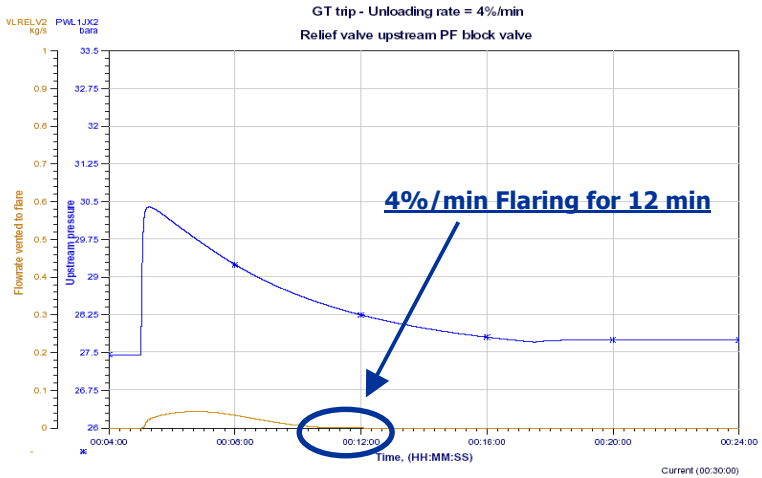
Case Study Pre-FEED - Evaluation of gasifiers unloading ramp after the GT Trip









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The Design Tools: Dynamic Simulation and Electrical Studies

FEED Phase: Compliance with the Grid Prescriptions

Even if the intrinsic characteristics of the IGCC technology would require a base load operation, the plan is requested to meet the grid code prescriptions (specific for each Country) which are mainly related to the frequency control

Frequency Control

- Generated power shall balance absorbed power: no accumulation of electric power is possible
- A constant frequency is the result of generated power = absorbed power
- Constant frequency= high quality level of electric power

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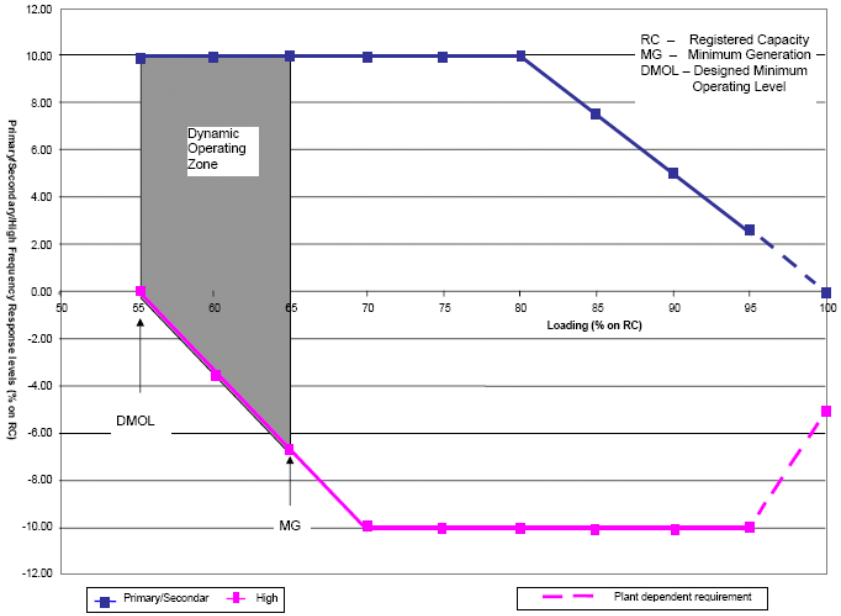
The Design Tools: Dynamic Simulation and Electrical Studies

UK Grid Code - Minimum Frequency Response Requirement Profile

(diagrammatically for a 0.5 Hz change in Frequency)



Primary Frequency Control

- allows to continuously balance generated and absorbed power, by automatic modulation of the generated power
- Very short response time required – Action by automatic speed governors of machines

The IGCC plant should be capable to provide Primary Frequency response at least to the solid boundaries shown in the figure (NG cofiring or syngas storage are the only options)

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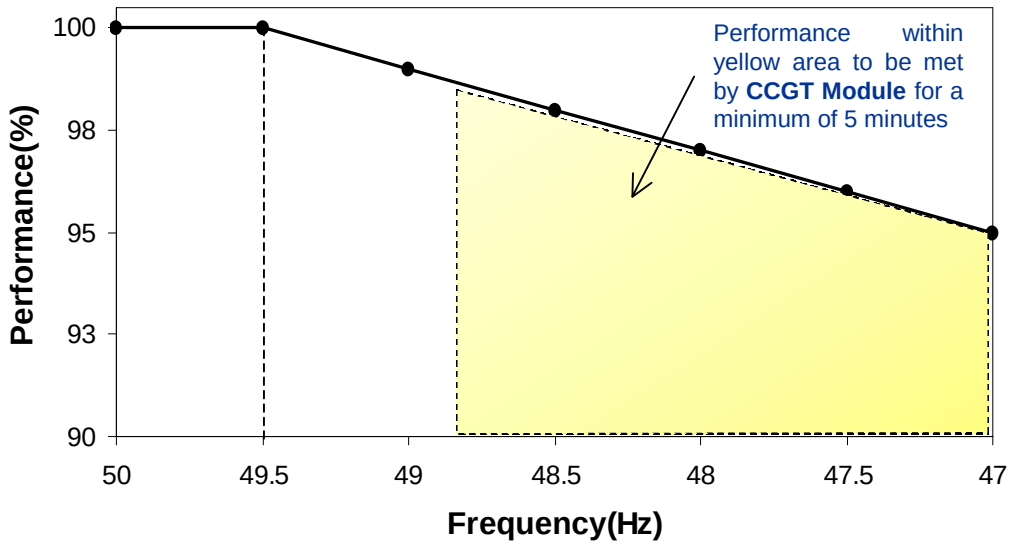
The Design Tools: Dynamic Simulation and Electrical Studies

UK Grid Code – Performance under Frequency Variation

Secondary Frequency Control

- allows to restore the frequency deviation to its nominal value and to restore the power exchanges from interconnected grid to the planned figure
- Response time lower than primary frequency control – Action by modification of power output set-point of the machines via a signal coming from the TSO



Performance(%)= NPO actual/ NPO@50Hz, n.c

NPO= Net Active Power Output

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Grid Prescriptions: What to do with an IGCC Plant?

In a plant designed according to the process units approach the response time is stated by the response of the entire chain of syngas production: it is difficult to generate more syngas in a very short time

- Possible options to be investigated:
  - Deviation from mandatory prescriptions (e.g. IGCC operated a base load plant, no contribution or partial contribution to frequency control)
  - Storage of syngas (buffer)
  - Reduction of Post Firing in HRSG to make available more syngas to GT
  - Load shedding on large electric motors on IGCC plant (e.g. CO_2 compressors, etc)
  - Action on GT (overfiring, natural gas cofiring, air bleed, etc)
- Each options or options combination shall be compared from a technical and investment cost point of view
- Impact on gas turbine life cycle and maintenance to be analyzed

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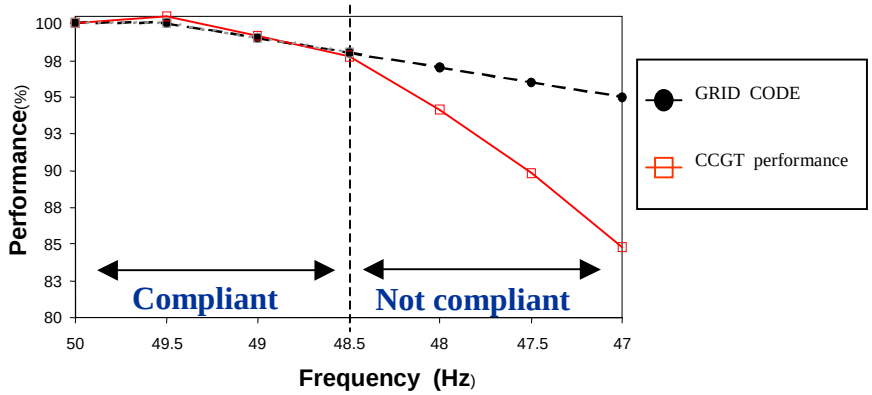
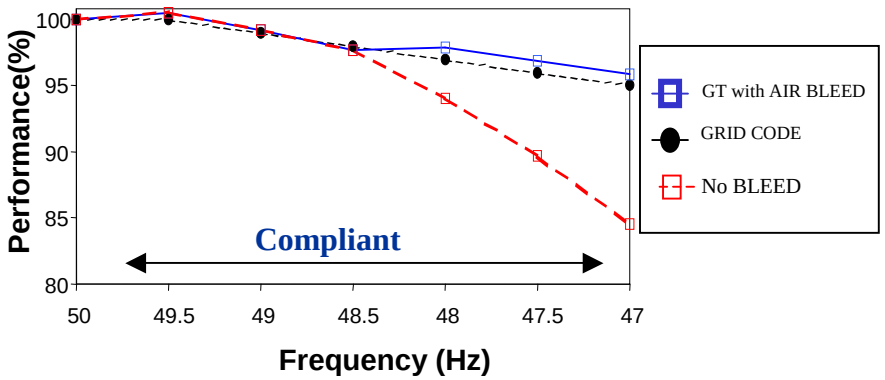
The Design Tools: Electrical Studies

CCGT Frequency Response vs UK Gride Code

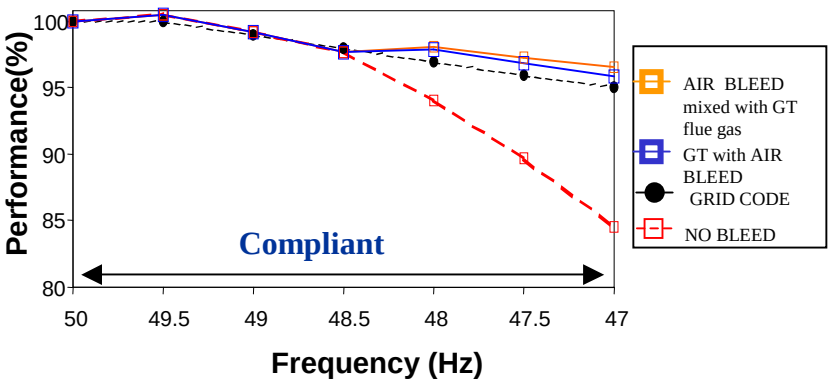


CASE 1: CCGT normal response (GT and ST output decrease)

- Gas turbine has a different behaviour at different ambient temperatures
- Steam Turbine power output changes, depending on GT exhaust energy and PF duty (if any)



CASE 2: With Air Bleed (to vent) on Gas Turbine



CASE 3: With Air Bleed mixed with GT flue gas

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The Design Tools: Dynamic Simulation and Electrical Studies

- Voltage Level Selection and Network Reliability Study
  - optimize IGCC electrical network on the basis of Process Units needs
  - individuate the arrangement capable to minimize IGCC total or partial shutdown at a certain investment cost increase
  - Check the payback time
- Transient Stability Study
  - investigate critical time of generators and larger users (e.g. ASU compressors and CO_2 compressors) during internal or external failure or disturbance, to prevent partial or total IGCC shut-down
  - investigate IGCC behaviour after disconnection from the external grid (island operation)

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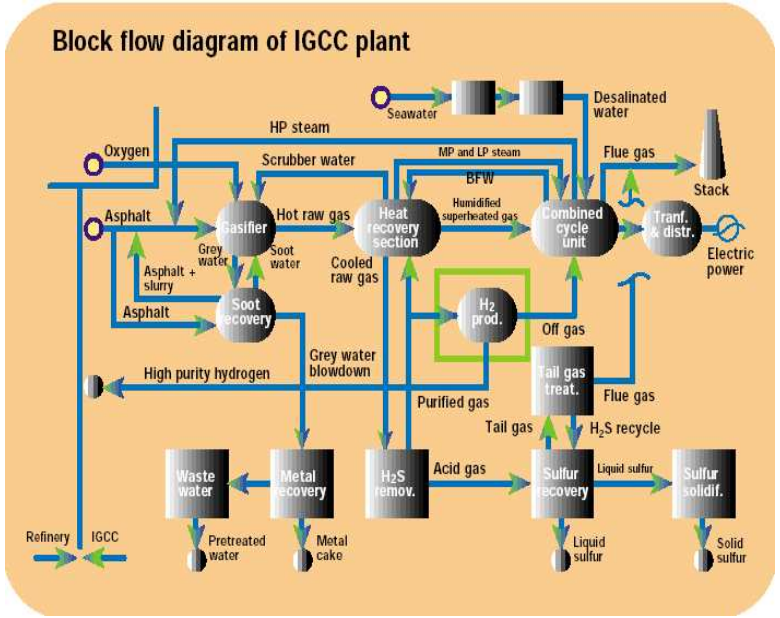
Case Study: ISAB Energy 550 MWe IGCC (asphalt)

FOSTER WHEELER ITALIANA SCOPE OF WORK

- Feasibility Study
- Optimization Study
- Front End Engineering Design
- EPC (shared with SP)
- Commissioning and Start-up (shared with SP)
- Performance Test Procedure
- Dynamic Simulation Study during EPC (both process and electrical)
- Control System Design and DCS/ESD supply
- Electrical System Design
- Feasibility Study for Retrofit to CO_2 capture



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Case Study: ISAB Energy 550 MWe IGCC (asphalt)

Outcomes of the Dynamic Simulation Study

- Equipment Mechanical Design (i.e. geometrical dimensions, design temperature and pressure) and control valves size and characteristics have demonstrated to be adequate

- Control Philosophy: the logics of the Master Controllers (i.e. IGCC Master Controller, CCU Master Controller, Gasification Master Controller) have been validated. Some logics to withstand emergency conditions have been modified

- Controllers parameters defined through the simulations have been successfully implemented during plant commissioning

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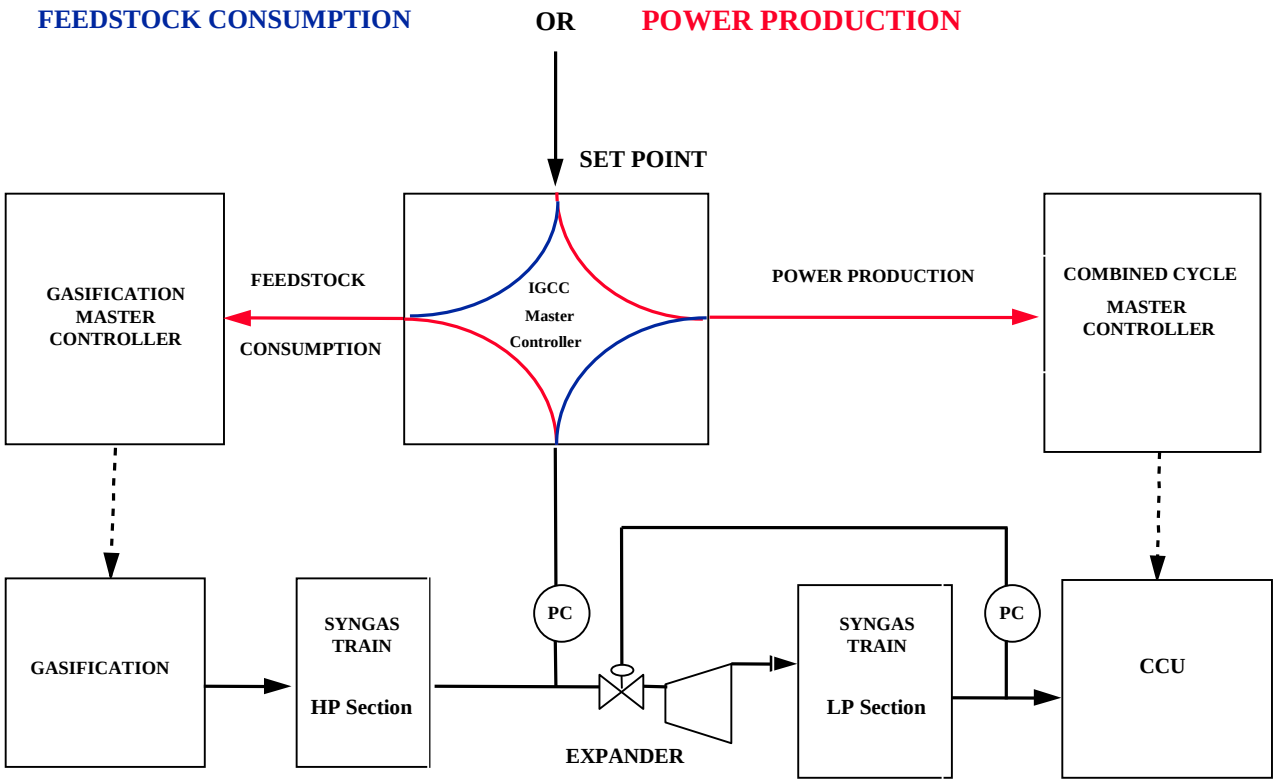
Case Study: ISAB Energy 550 MWe IGCC (asphalt)

IGCC Normal Operating Control Modes



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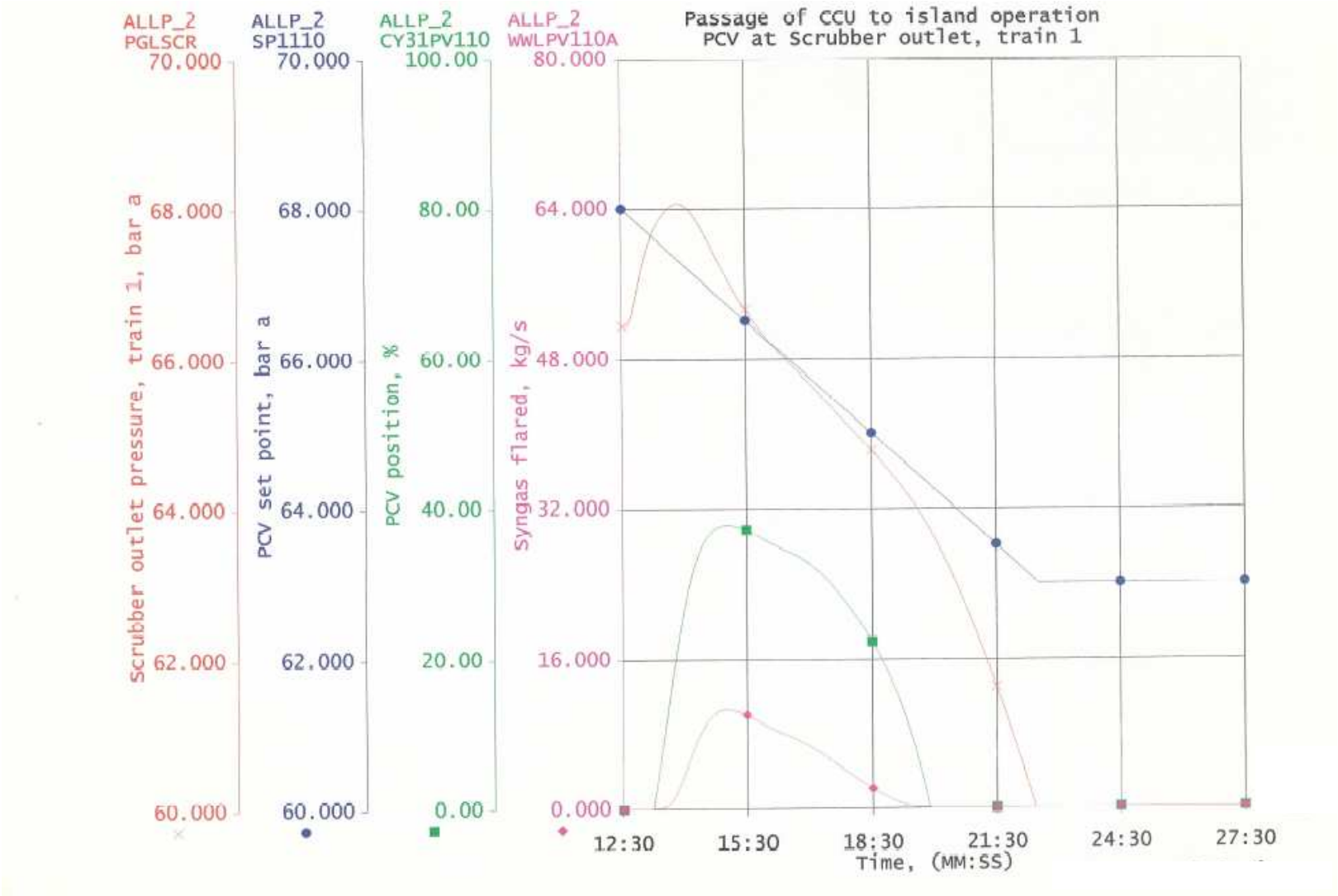
ISAB Energy – Passage of CCU to Island Operation – PCV at scrubber outlet opening



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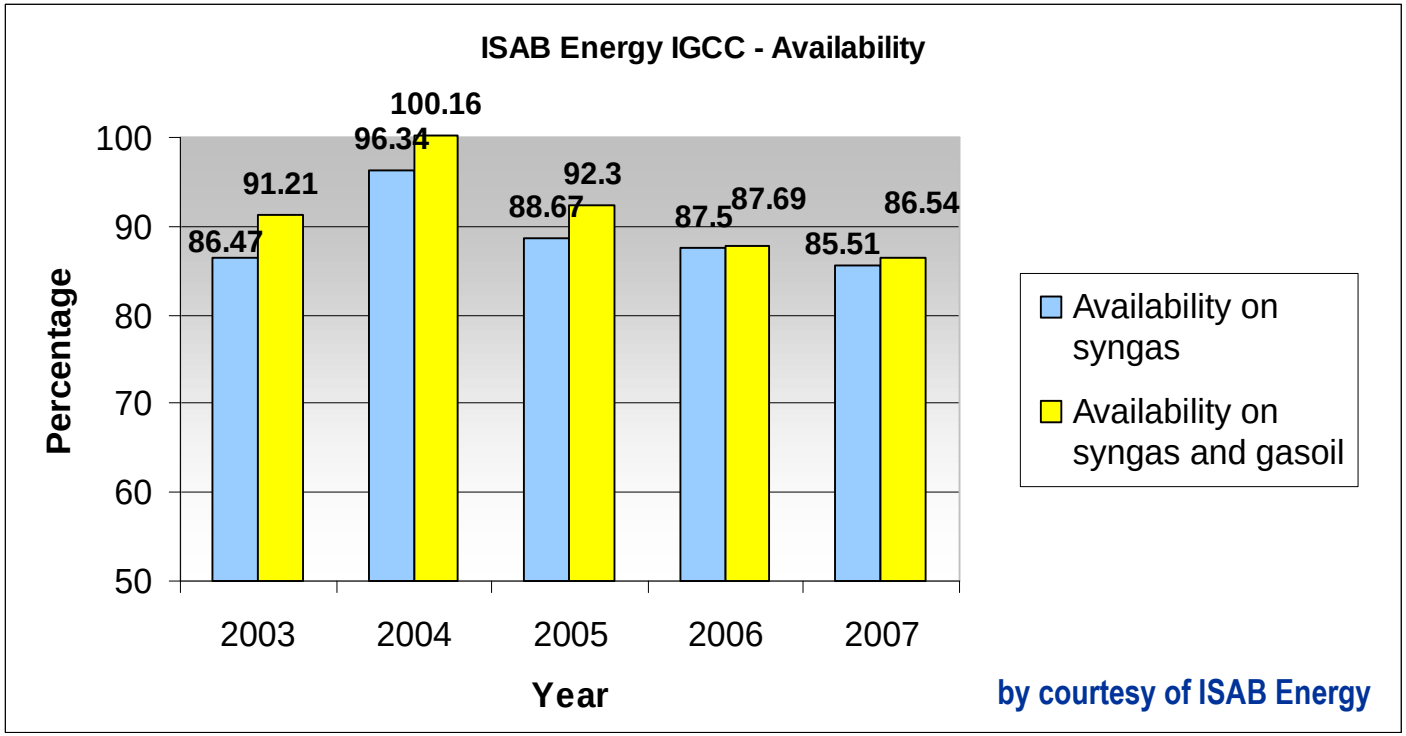
Case Study: ISAB Energy 550 MWe IGCC (asphalt)

Plant Performance and Availability



by courtesy of ISAB Energy

Excellent Reliability starting from the first operation mainly due to the robust control system

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Case Study: ISAB Energy 550 MWe IGCC (asphalt)

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Case Study: api energia 285 MW IGCC Project

- Location: adjacent to api Refinery – Falconara (AN)
- 285 MW net power output / feedstock visbroken vacuum residue (60 t/h)
- GE Energy/Texaco gasification quench high pressure with naphtha soot recovery
- Selexol and COS hydrolisis for syngas sweetening
- Combined Cycle with one gas turbine Alstom (ABB) 13E2
- LSTK contract by ABB who was also shareholder
- Entered commercial operation in April 2001

VERY POOR AVAILABILITY DURING FIRST YEARS OF OPERATION

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Case Study: api energia 285 MW IGCC Project

FOSTER WHEELER ITALIANA SCOPE OF WORK:

- consultancy services as Owner's Engineer during project execution, start-up and acceptance test;
- SIL evaluation;
- Reliability Improvement Program including Dynamic Simulation;
- Engineering and Construction of Upgrading modifications (Combined Cycle, IGCC Instrumentation and Control System etc);
- Feasibility Study for CO_2 capture
- Frame Agreement for other modifications signed every year

Dynamic Simulation aimed at implementation of an IGCC Master Controller, automatic switchover of the gas turbine from syngas to back-up fuel and start-up of the expander

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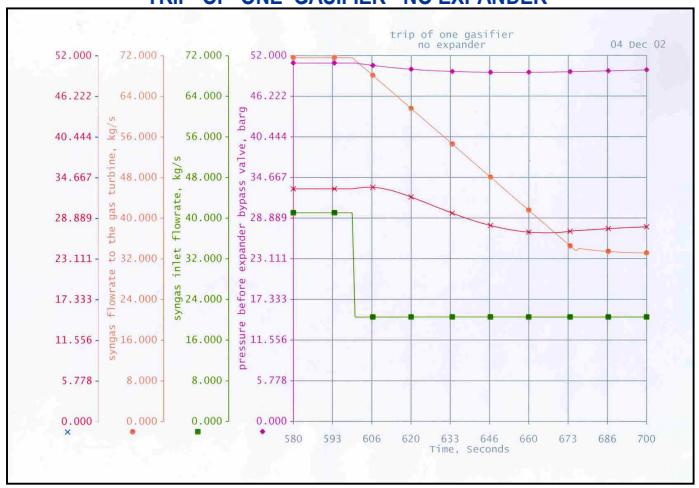
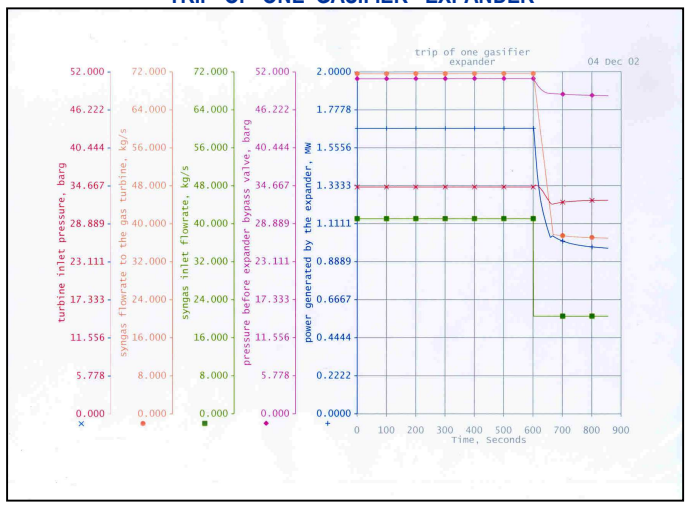
Case Study: api energia 285 MW IGCC Project

GT Automatic Switchover from Syngas to Back-up Fuel (Gasoil)

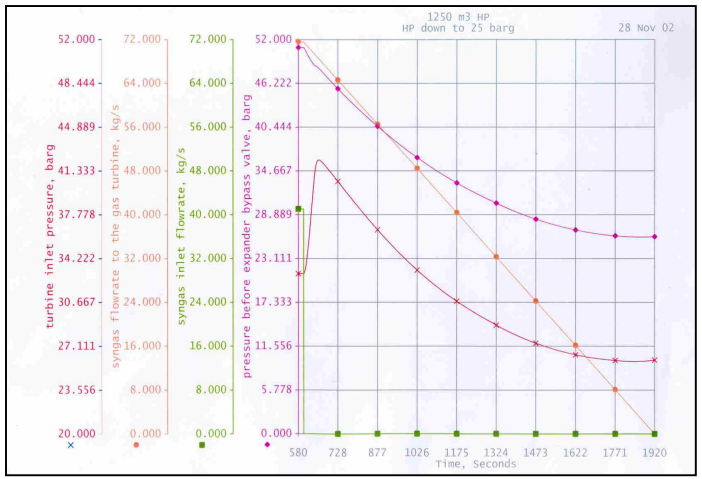
TRIP OF ONE GASIFIER - NO EXPANDER



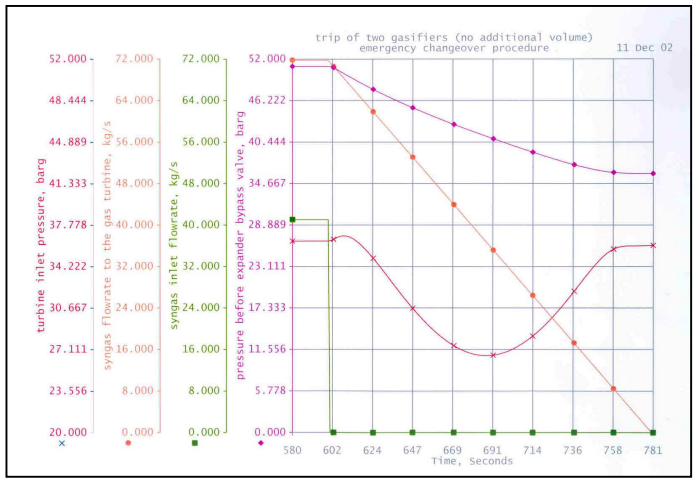
TRIP OF ONE GASIFIER - EXPANDER



1250 m^3 buffer HP – HP DOWN TO 25 BAR G



TRIP OF TWO GASIFIERS (no additional volume) - EMERGENCY CHANGE OVER PROCEDURE



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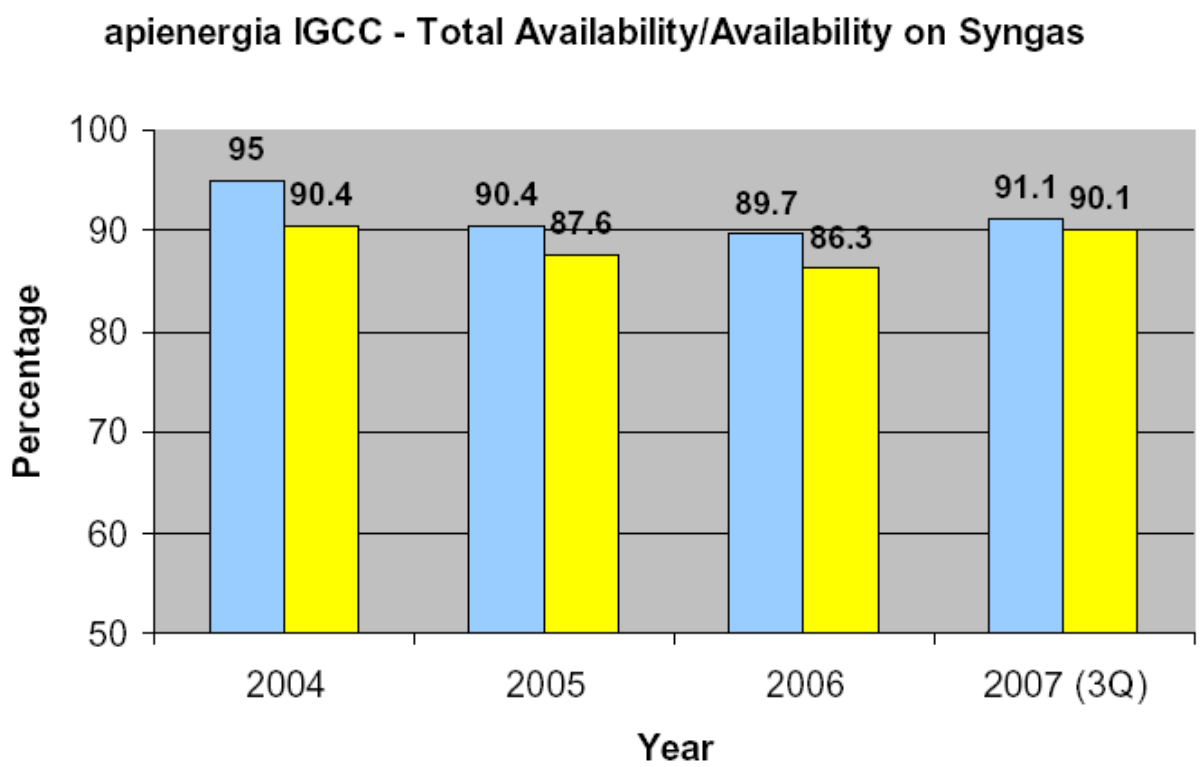
Case Study: api energia 285 MW IGCC Project



Year 2006 availability takes into account 35 days GT major overhaul (every 5 years)

by courtesy of api energia

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Case Study: api energia 285 MW IGCC Project

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Foster Wheeler Italiana Experience

Other References

- 5 FEED performed on oil and coal IGCC projects
- More than 35 IGCC and Gasification studies since 1988
- International Organization References (5 studies performed for IEA-GHG and 4 studies performed for EPRI)
- CO_2 capture: evaluation of impacts on plant performance and COE (Cost of Electricity)
- Hydrogen Co-production
- Coal to Chemicals/Coal to Liquids Projects
- Coal to Ammonia/Methanol (agreement with Casale)
- Coal to Syngas for iron ore reduction

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Foster Wheeler Italiana Experience

EPRI – Assessment of IGCC on Coal for Near-term Deployment

- Feasibility and optimisation study covering the "Engineering and economic assessment of IGCC coal power plants for near term deployment."
- PHASE 1: Technical and economic evaluation of forty IGCC designs, processing different coals (Pittsburgh # 8 and PRB) with five alternative gasification technologies (GE, KBR Southern Energy, Shell, Siemens), without with retrofitted carbon dioxide capture.
- PHASE 2: Technical and economic evaluation of eleven IGCC designs, processing different coals (Pittsburgh # 8 and Eastern Austrialian Bituminous Coal) with five alternative gasification technologies (GE, MHI, Shell, Siemens, Udhe, Prenflo), with and without carbon dioxide capture.
- This work is being performed as part of EPRI's CoalFleet for Tomorrow Programme, a collaboration involving more than 60 power industry companies to encourage the early deployment of advanced coal power generation technology.

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