RAM Development for Gasification and IGCC Plants

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Project Implementation
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Siemens Energy Sector – Answers for Energy Supply

Energy Products and Solutions - in 6 Divisions

- Oil & Gas
- Fossil Power Generation
- Renewable Energy
- Energy Service
- Power Transmission
- Power Distribution
Gasification Service Programs Available

The types of Service Programs for Gasification Projects range from Feasibility and FEED Studies to complete IGCC O&M and vary in content, timeframe, risk and rewards among others.

Solutions customized to the unique requirements of each project and customer.
Siemens Total Plant Service Approach

- Total plant approach
- O&M on entire plant
- R&D investment on the gasifier for diagnostics, sensor development and repair technology
- R&D investment on the entire Gasification plant to support project development and O&M
- One successful R&D Program is evaluating RAM - availability, reliability, output for gasification plants

Objectives of RAM R&D project

- Develop a modeling and computational approach to predict the availability and reliability of IGCC and Gasification plants
- Allow the flexibility to address many different plant configurations

Key Focus on Customer Economic Drivers of RAM
Objectives:
- Calculate RAM values
- Identify sensitivities and improvement opportunities
- Improve Tool with Diagnostic data

Tasks:
- Develop reliability analysis tool to flexibly evaluate the RAM values for different plant configurations
- Collaborate with key technology providers for each module to obtain detailed RAM data
- Improve with actual plant data

Objectives:
- Collect actual key plant performance data
- Improve availability and reliability

Tasks:
- Develop advanced sensors
- Improve rule basis for diagnosis

After 3 years the probability of a failure is almost 80%

Increasing Availability

Optimization Zone

Gasification R&D Optimization Cycle

RAM Analysis R&D

Optimized RAM Analysis

RAM Input from Diagnostics

Value of Spare Parts

Availability

99.8% 99.7% 99.6% 99.5% 99.4% 99.3% 99.2% 99.1%

Spare Parts Cost = f(Availability)

100,000 $

Loss of Revenue = f(Availability)

Total Cost

Determined by Costumer

Optimization Zone
Expected Availability of the Plant Through RAM (Reliability, Availability and Maintainability)

Determine Expected Values

- **Reliability factor**
  \[ RF \% = \frac{MTBF}{MTBF+MDT} \]

  *MTBF*: Mean time between failures
  *MDT*: Mean down time after forced outage

- **Availability**: Reliability plus Planned Maintenance

Distribution of Probability

- Monte Carlo simulation of probability distribution

- Uncertainty due to:
  - Limited observation periods
  - Inaccurate input data

The probability to reach at least 92% reliability is over 90%
RAM Optimization

Reliability Sensitivities

- Assess components with high / low sensitivities
- Sensitivity: component $i$ with respect to the system $\frac{dRF}{RF}/\frac{dRF_i}{RF_i}$

$RF$: Reliability Factor

Availability Optimization through:

- Maintenance schedule coordination across all systems
- Spare parts stocking and repair planning

Sensitivities and Optimization: Reliability versus Cost

Increasing Availability

Determined by Customer

Loss of Revenue $= f(Availability)$

Total Cost

Spare Parts Cost $= f(Availability)$

Value of Spare Parts

100,000 $
## Gasification / IGCC Modules: Overview of Plant Modules

<table>
<thead>
<tr>
<th>Input</th>
<th>Gasification &amp; Controls</th>
<th>Gas Treatment</th>
<th>Gas Cleaning</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Milling and Drying</td>
<td>Controls [Siemens T-3000 Plant System]</td>
<td></td>
<td>Claus Plant CO₂ Removal</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Methanation</td>
</tr>
</tbody>
</table>
Reliability and Availability Analysis: Modeling of System Structure

Identification of possible failures with impact on reliability and availability

- Failure modes and effects analysis (FMEA) for single faults
- Fault tree analysis (FTA) for failure correlations
- Markov models to describe consecutive failures

ZUSIM - Siemens Tool for Fault Tree Analysis and Markov Chains
Evaluation of Reliability Models

- Evaluation of field experience on system level
- Comparison with calculated values for system and subsystems

Calculation of **system** reliability: MTBF, MDT → RF

- Evaluation of reliability structure model
- Input in reliability model
- Assessment of component reliability

Dual Approach Results in More Accurate Models

Calculation of **component** reliability: MTBF, MDT → RF
Calculation of RAM Values for Gasification / IGCC
Case I – Configuration No Redundancy

System Output

- Air Separation Unit
- Coal Mill
- Silo
- 4 hours capacity
- Gasification Line
- BWS
- 4x33%
- Sour Shift
- Acid Gas Removal
- Claus Plant
- CO₂ Compression
- Methanation
- Combined Cycle
  2 GT, 1ST, Multi-Shaft, Modular Fuel System
Calculation of RAM Values for Gasification / IGCC
Case I – Redundant Configuration Methanization Only

Air Separation Unit

2x50% Coal Mill
4 hours capacity
Coal Mill

Gasification Line
Gasification Line
Gasification Line
Gasification Line

MIN

Silo
Silo

4x33%

CO₂ Compression

Methanation 2x60%

Methanation

Claus Plant

Acid Gas Removal

Sour Shift

System Output

Combined Cycle
2 GT, 1ST, Multi-Shaft, Modular Fuel System
Example Results Case I: Plant Output for Non-Redundant vs. Redundant Configuration

The redundant Methanization configuration shows 0.5% equivalent availability improvement

### Basic Configuration RF: 90.4%

<table>
<thead>
<tr>
<th>Module</th>
<th>Is included?</th>
<th>Basic-RF</th>
<th>Sensitivity</th>
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<tbody>
<tr>
<td>Gasification</td>
<td>yes</td>
<td>98.29%</td>
<td>0.00</td>
</tr>
<tr>
<td>Milling</td>
<td>yes</td>
<td>98.59%</td>
<td>0.00</td>
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<tr>
<td>ASU</td>
<td>yes</td>
<td>98.76%</td>
<td>0.00</td>
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<tr>
<td>Shift</td>
<td>yes</td>
<td>99.04%</td>
<td>0.00</td>
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<tr>
<td>Acid Gas Removal</td>
<td>yes</td>
<td>99.40%</td>
<td>0.00</td>
</tr>
<tr>
<td>Claus Plant</td>
<td>yes</td>
<td>98.83%</td>
<td>0.00</td>
</tr>
<tr>
<td>CO2_Compression</td>
<td>yes</td>
<td>99.80%</td>
<td>0.00</td>
</tr>
<tr>
<td>Methanation</td>
<td>yes</td>
<td>97.28%</td>
<td>1.00</td>
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</tbody>
</table>

### Redundant Configuration RF: 90.9%

<table>
<thead>
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<th>Module</th>
<th>Is included?</th>
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<th>Sensitivity</th>
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<tbody>
<tr>
<td>Gasification</td>
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<td>98.29%</td>
<td>0.24</td>
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<tr>
<td>Milling</td>
<td>yes</td>
<td>98.59%</td>
<td>0.10</td>
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<td>ASU</td>
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<td>98.76%</td>
<td>0.04</td>
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<tr>
<td>Shift</td>
<td>yes</td>
<td>99.04%</td>
<td>0.00</td>
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<td>Acid Gas Removal</td>
<td>yes</td>
<td>99.40%</td>
<td>0.00</td>
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<td>yes</td>
<td>98.83%</td>
<td>0.00</td>
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<tr>
<td>CO2_Compression</td>
<td>yes</td>
<td>99.80%</td>
<td>0.00</td>
</tr>
<tr>
<td>Methanation</td>
<td>yes</td>
<td>97.81%</td>
<td>0.77</td>
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</table>
Calculation of RAM Values for Gasification / IGCC
Case II – Configuration of No Redundancy

Air Separation Unit

2x50% capacity
Coal Mill
Silo

4 hours capacity
Gasification Line
Gasification Line
Gasification Line
Gasification Line

MIN

Silo
Coal Mill

CO₂ Compression
Methanation

Combined Cycle
2 GT, 1ST, Multi-Shaft, Modular Fuel System

System Output

4x25%

Sour Shift
Acid Gas Removal
Claus Plant
Calculation of RAM Values for Gasification / IGCC
Case II – Redundant Configuration for all Systems Except Gasifier
Example Results
Plant Output for Non-Redundant vs. Redundant All Modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Is included?</th>
<th>Basic-RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification</td>
<td>yes</td>
<td>96.16%</td>
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<tr>
<td>Milling</td>
<td>yes</td>
<td>98.59%</td>
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<tr>
<td>ASU</td>
<td>yes</td>
<td>98.76%</td>
</tr>
<tr>
<td>Shift</td>
<td>yes</td>
<td>99.04%</td>
</tr>
<tr>
<td>Acid Gas Removal</td>
<td>yes</td>
<td>99.40%</td>
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<tr>
<td>Claus Plant</td>
<td>yes</td>
<td>98.83%</td>
</tr>
<tr>
<td>CO2_Compression</td>
<td>yes</td>
<td>99.80%</td>
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<tr>
<td>Methanation</td>
<td>yes</td>
<td>97.28%</td>
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</tbody>
</table>

Basic Configuration: 85.49%

<table>
<thead>
<tr>
<th>Module</th>
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</thead>
<tbody>
<tr>
<td>Gasification</td>
<td>Yes</td>
<td>96.16%</td>
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<tr>
<td>Milling</td>
<td>yes</td>
<td>99.61%</td>
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<tr>
<td>ASU</td>
<td>yes</td>
<td>99.00%</td>
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<td>Shift</td>
<td>yes</td>
<td>99.84%</td>
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<tr>
<td>Acid Gas Removal</td>
<td>yes</td>
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<td>Claus Plant</td>
<td>yes</td>
<td>99.52%</td>
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<tr>
<td>CO2_Compression</td>
<td>yes</td>
<td>99.06%</td>
</tr>
<tr>
<td>Methanation</td>
<td>yes</td>
<td>97.81%</td>
</tr>
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Redundant Configuration: 87.83%

The redundant configuration shows more than a 2% equivalent availability improvement but with a steep increase of capital cost.
Conclusions on Example Calculations

Alternative Comparison
- Basic configuration typical arrangement
- In the redundant configuration gasification island is held constant and other modules add redundancies

Results
- The redundant configuration shows more than 2% better total expected output than the basic configuration
- The results show how the Siemens RAM model can assist in the feasibility stages to easily evaluate the availability effects of different plant configurations
Conclusions for Siemens Service RAM R&D Development Program

The RAM Tool:
- Is an accurate tool for predicting Plant Equivalent Availability and Reliability
- Is particularly valuable during feasibility studies
- Is applicable for any plant configuration

The Modular RAM Approach:
- Is flexible for many applications
- Offers wide and expandable configuration options
- Calculates sensitivities to pinpoint highest reliability impacts

The RAM Tool allows to evaluate project alternatives to optimize performance and project financial returns
Thank You!

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