Application of MATLAB/Simulink for 1 Dimensional Multi-physics Analysis

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LS Electric, Electrotechnology R&D Center
HyunWoo Joo
LS Group is a conglomerate based in South Korea. It spun off from LG Group in 2003. LS is leading in the field of electric power, automation, machinery, materials and energy.

**LS Group**

- **Employees**: 12,700
- **Affiliates**: 48
- **Sales**: 22.9 B USD
- **Total Asset**: 22.6 B USD

**LS Electric**

- **Employees**: 3,500
- **Sales**: 1.9 B USD
- **Operation Income**: 150 M USD

*Financial figures in 2019*
**Power Solution | Systems | HV S/S System**

LS ELECTRIC manufacture the PDPS which constantly monitors the functions and performances of major power facilities including GIS and HV TR of HV power systems.

<table>
<thead>
<tr>
<th>Management S/W Platform</th>
<th>Gas Insulated Switchgear</th>
<th>HV Power Transformer</th>
<th>MV Switchgear (MCSG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCADA system (POMS, PDPS, SAS, ECMS)</td>
<td>Up to 420kV / 63kA / 6300A</td>
<td>Up to 550kV 800MVA</td>
<td>Up to 36kV / 50kA / 5000A</td>
</tr>
<tr>
<td>Substation Automation Sys.</td>
<td></td>
<td>Special purpose: Scott connection, Electric furnace, Shunt reactor, HVDC converter transformer</td>
<td></td>
</tr>
</tbody>
</table>

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[Image of SCADA system, DAU, and Gas Insulated Switchgear]
Gas Insulated Switchgear (GIS)

• Gas insulated switchgear
  A compact, multicomponent device, enclosed in a grounded metallic case in which the basic insulating medium is SF₆ gas and which typically includes buses, switches, circuit breakers, and other related devices. One of the basic functions of GIS is protection, which is interruption of short-circuit and overload fault currents while maintaining service to unaffected circuits. GIS also provides isolation of circuits from power supplies.

• Compact design
  - Space saving compact design minimize footprint and gas amount
  - Easy handling and maintenance by Modular Design

• High Reliability & Safety
  - Rigorously verify the reliability of product using testing facilities in PT&T (Test Lab.)
  - Improves reliability by design verification with advanced analytical CAE Tools

• Manufacturing System
  - Clean system manages prevention of Particle entrapment and control quality
  - Flexible manufacturing system enables short delivery and different needs response

• Function of GIS

Fault ➔ Fault Detecting ➔ Opening Contact ➔ Eliminating Arc ➔ Isolation of Circuit ➔ Prevent Accidents
### GIS Product Line-up

<table>
<thead>
<tr>
<th>Voltage</th>
<th>25.8/36kV</th>
<th>72.5kV</th>
<th>145kV</th>
<th>170kV</th>
<th>245kV</th>
<th>362kV</th>
<th>420kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Voltage</td>
<td>25.8/36</td>
<td>72.5</td>
<td>145</td>
<td>170</td>
<td>245</td>
<td>362</td>
<td>420</td>
</tr>
<tr>
<td>Rated Current [A]</td>
<td>~3150</td>
<td>2000</td>
<td>~3150</td>
<td>~3150</td>
<td>~3150</td>
<td>~3150</td>
<td>~3150</td>
</tr>
<tr>
<td>Rated Breaking Current [kA]</td>
<td>~40</td>
<td>20/31.5</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Rated Making Current [kA]</td>
<td>~100</td>
<td>50/79</td>
<td>100/104</td>
<td>100/104</td>
<td>100/104</td>
<td>100/104</td>
<td>100/104</td>
</tr>
<tr>
<td>Power Frequency Voltage [kV]</td>
<td>70</td>
<td>140</td>
<td>275</td>
<td>50</td>
<td>130</td>
<td>325</td>
<td>750</td>
</tr>
<tr>
<td>LIWL [kV]</td>
<td>170</td>
<td>325</td>
<td>650</td>
<td>4000</td>
<td>6300</td>
<td>650</td>
<td>650</td>
</tr>
</tbody>
</table>

![GIS Product Line-up Diagram](image_url)
Project Overview

- SF6 Gas
- Conventional design process
- Test experience → easy to improve

- Eco-friendly gas
- New design concept & process
- Difficult to estimate performance

➢ Need for concept study in the beginning stage of design
➢ Optimal design between mechanism and chambers in GIS
➢ Reduction of trial & error and calculation time by 2D/3D analysis
Overall 1D Analysis Model

- Trip Coil
- Mechanism
- Dual Motion
- Contact Separation
- Arc Extinction

- <Trip Coil>
- <Mechanism & Link Assembly>
- <Dual Motion>
- <CB Interrupter>
### Mechanism Model

1. Closing spring
2. Trip spring
3. Fly wheel
4. Trip latch
5. Closing latch
6. Closing chain
7. Motor

#### Components:
- Spring
- Cylindrical Solid
- File Solid
- Revolute Joint
- Latch
- Cam
- Spatial Contact Force
- Roller

#### Actions:
- Spring Charging
- Closing
- Opening
Dual Motion & Chamber Model

<Compression Chamber>
(Variable Volume $\Delta V_1$)

<Back flow channel>
(Fixed Volume $V_2$)

<Tank>
(Fixed Volume $V_3$)
Valves & ODP

- Check Valve
- Relief Valve
- ODP Block

Diagram showing various components and their interactions.
No Load Simulation (Stroke & Pressure)
No Load Simulation Results

• Comparisons with experimental results

- Expansion and Compression Pressure [bar]
- Stroke [mm]

• 1D Results (Strokes, Temperature & Pressures)

- Check Valve Stroke [mm]
- Expansion and Compression Volume [mm$^3$]
- Expansion and Compression Density [kg/m$^3$]
- Expansion and Compression Temperature [K]
- Expansion and Compression Mass [kg]
- Sub and main nozzle Cross-Section Area [mm$^2$]
Arc Extinction (Load Analysis)

Fault Current ➔ Opening Contact ➔ Compression Chamber ➔ Expansion Chamber ➔ Arc Analysis & Gas Properties ➔ Pin & Tulip (Cooling Chamber) ➔ Tank
Arc Modeling

<table>
<thead>
<tr>
<th>Items</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc Plasma</td>
<td>Thermodynamic quantities of Arc Plasma</td>
</tr>
<tr>
<td>Arc Model</td>
<td>Arc voltage and Arc Energy</td>
</tr>
<tr>
<td>Radiation Model</td>
<td>Amount of energy released by radiation and absorbed by nozzle material</td>
</tr>
<tr>
<td>Ablation Model</td>
<td>Ablated mass distribution</td>
</tr>
<tr>
<td>Arc Heating Coefficient</td>
<td>Amount of energy transferred to each chamber</td>
</tr>
<tr>
<td>Cooling Model</td>
<td>Amount of energy removed from cooling and dissociation</td>
</tr>
<tr>
<td>Electric Current Model</td>
<td>Electrical current for three phase</td>
</tr>
</tbody>
</table>
Load Simulation Results

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Arcing Time</th>
<th>Current (Duty)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal</td>
<td>10ms</td>
<td>20%</td>
</tr>
<tr>
<td>O1</td>
<td>12.7ms</td>
<td>90%</td>
</tr>
<tr>
<td>O2</td>
<td>11.6ms</td>
<td>90%</td>
</tr>
<tr>
<td>O3</td>
<td>10.4ms</td>
<td>100%</td>
</tr>
<tr>
<td>O4</td>
<td>22.9ms</td>
<td>90%</td>
</tr>
<tr>
<td>O5</td>
<td>15.9ms</td>
<td>90%</td>
</tr>
<tr>
<td>O6</td>
<td>19.9ms</td>
<td>90%</td>
</tr>
</tbody>
</table>

< Test Input current>

< Current and Voltage>

< Element Block >

< Change of Nozzle Diameter with successive test>

< O3 Pressure>
1D Simulation for GIS Products

Simulation Time: 0.1

Simulation Start

- 25.8/36kV
- 72.5kV
- 145kV
- 170kV
- 245kV
- 362kV
- 420kV

Mechanism: 145kV (OPEN)
Link: Link (SP)
CB: Fork Type
Conclusion

[R&D Speed-Up]

2D/3D Analysis

- Need for 3D model and Time-consuming calculation time
- Technical difficulty in coupled real-time simulation between dynamics and arc simulation

1D Analysis

- Best solution for coupled real-time simulations

[Design parameter Optimization]

3D 1D analysis process

- Modeling (3D Import & Modification)
- B.C and Material
- Solving (600min/1case)
- Solving (20min/1case)

Select design candidates

Calculation time comparison for 100 case Models

- Calculation time [H] : 93% reduction
- Modeling [H] : 94% reduction
Future Plan

Excel based

Simulink Compiler
Thank you for your attention