Gearing up to meet Africa’s rising power and water demand

Vikas Dabeer
Director - Business Development
Applied Materials India Pvt. Ltd
India

http://www.appliedmaterials.com/technologies/fault-current-limiters
### Applied Materials Global Strength

<table>
<thead>
<tr>
<th><strong>APPLIED MATERIALS INC</strong></th>
<th><strong>APPLIED MATERIALS INDIA PVT LTD</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Market Cap:</strong> $29.16 billion</td>
<td>Founded: June, 2002</td>
</tr>
<tr>
<td><strong>Fiscal 2014 Revenue:</strong> $9.1 billion</td>
<td>Headquarters: Bangalore, India</td>
</tr>
<tr>
<td><strong>Fiscal 2014 R&amp;D:</strong> $1.4 billion</td>
<td>India Presence: Chennai, Delhi, Mumbai</td>
</tr>
<tr>
<td><strong>Founded:</strong> November 10, 1967</td>
<td>Lab Space: &gt; 25,600 sq. ft.</td>
</tr>
<tr>
<td><strong>Headquarters:</strong> Santa Clara, California</td>
<td>University Spend: &gt; INR 75 CR</td>
</tr>
<tr>
<td><strong>Global Presence:</strong> 84 locations in 18 countries</td>
<td>Employees*: ~ 2300</td>
</tr>
<tr>
<td><strong>Fortune 500 Ranking:</strong> 302</td>
<td><strong>RD&amp;E and/or Manufacturing Centers:</strong> China, Germany, India, Israel, Italy, Singapore, Taiwan, United States</td>
</tr>
<tr>
<td><strong>Employees:</strong> ~13,700 worldwide</td>
<td><strong>Employees:</strong> ~13,700 worldwide</td>
</tr>
<tr>
<td><strong>Patents:</strong> ~10,400 issued</td>
<td><strong>Patents:</strong> ~10,400 issued</td>
</tr>
</tbody>
</table>

*Including RFTs, contractors & associates

Data as of Oct 7th 2014
Commercial FCL Progress

- Installed 2 SCFCL into the grid (US). Limited 15 faults. Systems have 100% uptime.

- Introduced solid state fault current limiter (SSFCL)
  - Medium voltage system
  - Flexible modular approach

- Installed a SSFCL into the grid in Ausnet (Australia)

- Contract with Asian Customer for 2 Transmission class FCL – First Commercial Sales

- In final contract negotiations for 3 separate site installs of SCFCL’s and SSFCL’s (total of 6 fault current limiters).

- In funding approval for a 220KV FCL system in India

- In discussions with customers for up to 500 KV fault current solutions

115 KV FCL – Commission 3/16

www.african-utility-week.com | www.clean-power-africa.com
Drivers of the Fault problems

Economic Growth and Large Investments in Distributed Generation are driving new Grid Architectures. Fault currents are rising.

New Generation
- Renewable energy – wind, solar, hydro
- Increased grid interconnection

Increased demand
- Urbanization - Population growth
- Transportation - Electric cars, trains

Increased Fault Current Level
Fault Currents are Destructive

- Large fault currents can cause the grid to fail catastrophically
- Even small fault currents can damage the grid’s capital infrastructure
  - Age equipment
  - Premature failures
  - Performance degradation
## Scenarios for use of FCLs

<table>
<thead>
<tr>
<th>Driver</th>
<th>SCFCL Role</th>
<th>Benefit to customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase Substation Capacity</td>
<td>Limit FC on system and allow more generators to be connected</td>
<td>Defer capital expenditures on new substation or Equipment</td>
</tr>
</tbody>
</table>
Current options to mitigate Fault Currents

- Utility over-engineer system
- Introduce mitigations with detrimental impact

<table>
<thead>
<tr>
<th>Mitigations</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Splitting ($$)</td>
<td>Reduces flexibility and reliability</td>
</tr>
<tr>
<td>High impedance transformers ($$$)</td>
<td>Increases transformer cost and losses</td>
</tr>
<tr>
<td>Current Limiting Reactors ($$)</td>
<td>Increases active and reactive power loss, voltage drops causing voltage stability issues</td>
</tr>
<tr>
<td>Breaker &amp; Busbar Upgrades ($$)</td>
<td>High sub-station down-time and cost</td>
</tr>
<tr>
<td>New Substations ($$$$)</td>
<td>High cost of land &amp; new cable lines</td>
</tr>
</tbody>
</table>

Current Solutions are non-optimum and may require additional mitigation
System Benefits of Fault Current Limiters

- Applied Materials FCL neutralizes the effects of fault current on grid architecture
- Since fault currents dictate much of the grid design and equipment configuration today, neutralizing fault currents creates greater flexibility in grid design and component selection enabling:
  - Safety, Arc Flash Reduction, Brush Fire Suppression
  - Increased substation capacity
  - Easier addition of new generation
  - Protecting key assets
  - Easier interconnection of distributed generation
  - A more reliable and resilient grid
Desired Characteristics of an Ideal FCL

- An Ideal Fault Current Limiter would
  - In normal operation, it is virtually "transparent" (no power or voltage loss) to the network
  - **Increase the impedance** on the line well before the first fault peak (when the most damage occurs)
  - Diminish the fault current by at least a factor of 2 for its duration
  - Return the source impedance to its original value

- What is needed is a system that can move the electrical power from one circuit to another
  - At lower power: **Solid State**
  - At higher Power: **Superconductivity**

**Fault Current Limiters reduce Fault Currents Without the Need for Mitigation**

www.african-utility-week.com | www.clean-power-africa.com
Applied Materials Fault Current Limiter Platforms

• Transmission System FCL
  – Superconducting Fault Current Limiter (SCFCL)
  – 66 kV to 230 kV transmission voltage levels
  – > 1000 A load current
  – Up to 50% or higher fault current reduction

• Distribution System FCL
  – Solid State Fault Current Limiter (SSFCL)
  – Superconducting Fault Current Limiter – If required
  – Up to 45 kV distribution voltage levels
  – > 1000 A load current
  – Up to 50% or higher fault current reduction
How an SCFCL works

Normal operation
- Load current flows through superconducting unit
- SCFCL introduces nearly zero impedance and zero voltage drop

Fault Condition
- Superconductor inherently senses fault current, quenches, *inserts high resistance in ~ 1 ms*
- Current transfers to shunt and limits fault current

Recovery
- Superconducting unit recovers superconducting state quickly (seconds)

*Fault detection and current limiting is done with passive inherent superconductor properties – laws of physics rather than electronics*
How a SSFCL works

- Uses Solid state power electronics (IGBT’s) instead of Superconducting tape
- Does not require liquid nitrogen cooling
- Uses proprietary design concepts for Current, Voltage and Thermal management
- In normal operation $Z_{SS} \ll Z_{SH}$
- During fault $jX_{SS}$ increases and the current flows through the shunt reactor
Testing Methodology

• Understand Physics / Component Engineering and Test
  – iterations of designs; 1000’s of faults
  – Development of design guidelines
  – Failure mode validation and coverage

• Sub-System Validation and Test
  – Validate lab findings at a system level
  – Expose and correct any/all system level issues

• Full System Validation
  – Full system testing and validation at utility power levels
  – Customer requirement testing

Multiple Labs Enable Fast, Efficient Development and Learning
Fault Current Limiter Testing Performance

✓ Tested and qualified at 230 KV.

✓ 5 Weeks of KEMA Testing

✓ Lifetime Tested for 200 Bus Faults (>40 Years)

**KEMA 1** – Architecture Validation – The FCL works as designed
(Performance envelope to 125 KV, 56 kA and 60 % Reduction)

**KEMA 2** – System Performance – Controls, User Interface and refrigeration integration validated

**KEMA 3** – Life testing and Customer Validation  (>200 Fault Test)

**KEMA 4** – Component Characterization

**KEMA 5** – Product Platform Validation and System Optimization
Actual KEMA Test Results

KEMA Test Trial #46 - 12.5 kV and 56 kA rms (150 kA peak) Prospective Fault Current, limited to 24 kA rms (65 kA peak), 56% Current Reduction

- Fast response time < 1 ms
- 1st peak limitation
- 90% of Fault current flows through Shunt and only 10% flows through SC unit - Shunt protects SC unit

1st peak response within ~ 1 ms response time.
Validation of Simulation Results

KEMA Test

Simulation

Current Limiting Performance Test Results Agree with Simulation Results
Transmission Impulse test results

- Impulse test at 900 kV BIL
  - 15 Impulses at +900 kV – Pass
  - 15 Impulses at -900 kV – Pass
- AC withstand Voltage
  - 266 kV Single Phase (460 kV 3-phase)
  - 1 minute test at 266 kV – Pass
Subsystems with Latency or Redundancy are protected.
Need to focus on 4 key subsystems
System successfully installed, and online in June 2014.
System has demonstrated fault current capture and mitigation 15 times over past 1 year.
Fault Captured on July 8, 2014 - Detail

1. All is well...30 amp through unit
2. Fault occurs...SC current raises to 1000A and Shunt to 500A (4ms)
3. Next ½ cycle SC unit gets more resistive...SC unit is now less current than Shunt (2500A vs. 3750A)...current now shifted to limiting device
4. Fault Clears...Back to normal!

System Works and Clearly Shows System Operation / Performance
FCL Design Tradeoffs / Sensitivities

Major Items Influencing System Design are:
1. System Voltage
2. System Normal Current
3. Current Limiting Required

Each system requirement has system impacts:

- **System Voltage**
  - System voltage and limiting required determine the voltage drop across the FCL during fault

- **Normal Current**
  - FCL must be designed to handle that current full time

- **Limiting Required**
  - FCL adds impedance during fault. This translates to a Vdrop across the FCL

- **SC Unit Size**
  - Increased Cryo-loading

- **Reactor Size (Z_{FCL})**
  - Voltage Drop Required

- **Tank Size**
  - Tank Volume, Fill Frequency, Available Latency

- **# of Refrigerators**
  - Bulk
  - Active

www.african-utility-week.com | www.clean-power-africa.com
# Customer Inputs for FCL System Design

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Values</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selected Site Name / Location</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Voltage (3 phase Line-to-Line)</td>
<td>kVrms</td>
<td></td>
</tr>
<tr>
<td>Load Current – Continuous / Maximum</td>
<td>/ Arms</td>
<td></td>
</tr>
<tr>
<td>System MVA – Continuous / Maximum</td>
<td>/ MVA</td>
<td></td>
</tr>
<tr>
<td>Prospective Fault Current - Symmetric</td>
<td>kArms</td>
<td></td>
</tr>
<tr>
<td><strong>Ratio of Fault current to Max load current (Fault C/Max Load)</strong></td>
<td></td>
<td>Calculated by Applied</td>
</tr>
<tr>
<td><strong>Fault &amp; Recovery</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fault Duration Before Protection System Acts</td>
<td>Cycles</td>
<td></td>
</tr>
<tr>
<td>Required Fault Current Reduction – 1st peak</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Required Limited Fault Current - Symmetric</td>
<td>kArms</td>
<td></td>
</tr>
<tr>
<td>Impulse Voltage (BIL) Rating Requirement</td>
<td>kV</td>
<td></td>
</tr>
<tr>
<td>Switching Re-closure Sequence and Timing</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Site Selection and Logistics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance cycle at existing facility</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Contact details:

John_Ludlum@amat.com
Phone: +1-9782908967

Vikas_Dabeer@amat.com
Phone: +91-9686199484

http://www.appliedmaterials.com/technologies/fault-current-limiters