Notes from HV Power Converters Session

2/9/2010

ARPA-E Power Technologies Workshop

<u>Breakout Group</u>:

Grid-Scale High-Voltage Converters

(Chair: Mark Johnson, DOE ARPA-E)

What are the <u>drivers</u> (performance, cost, cooling, installation, etc) for higher voltage solid-state valves?

DC Requirement and Efficiency to Reduce Reactive Losses of AC
Controllability – LD Transmission would be enabled
Device Limitations – Incremental Si / 10X needed (speed,etc)
Real Estate Expense – HVDC Light cuts to 25%

New Generation Sources – Voltage Source Converter (Enabling Generation Mix Diversity)

Path of MVDC to Distribution Level: from Buildings up to Transmission

Sweet spots: voltages, topologies and architectures

Can these things be done in AC, with better power converter nodes as Substations?

Energy Efficiency – Before the meter (T&D deferral) as a system

Identify Low Hanging Fruit for System Pull Application (off-shore wind integration, eliminate wire down tower, HV conversion at the top of tower - 13.6kV at top, etc)

"There is no renewable resource that may be integrated to the grid without power electronics, including storage" – Group

Transformer-less Systems – (60Hz) to HF transformer systems enable switch adoption (form factor in magnetics)

- DC is required for transmission in the future; efficiency is key driver, reduce reactive losses; long-distance transmission that is controllable is key for widespread integration of renewables
- Further Si improvements are not in voltage, they are in speed
- Real estate is an issue for substations (footprint for classic HVDC); land costs are expensive, particularly in urban areas
- Can we identify “sweet spot” voltages and focus on those? 800kVDC to device level; others disagreed - focus on medium voltage (up to 13.6kV), high voltage, and UHV
- Do we have to do high voltage or could we stay high power? ARPA-E should look at all scales – buildings to transmission levels (full-scale)
- There are architecture levels, converter levels, and device levels
- Many of the things we’re talking about could be done with AC and power converters (AC-DC); power converter nodes as substations; patching existing system vs. migration to DC
- Substations are converters; long-term vision: HVDC (or AC with converters in substations as nodes)
- Key drivers: energy efficiency (how to measure?); power companies will support devices that increase efficiency because they save money “before the meter”
- By adding efficiency before the meter, do we reduce overall generation? Delay additions of capacity (T&D deferral); we need economic analysis here – we haven’t done these calculations to know what the precise value is of more efficient devices

What are the critical performance metrics for power converters at the HV and UHV scale?

- Reliability (years?) -30-50 Year or longer life for adoption

  - Reliability as Research – reliability from the start

- Power and blocking voltage for switches:

  MV → HV (sub-trans) → (HV trans) → UHV

  Higher Voltage Thyristor Valve and System Opportunities

  Eliminate 1C screw Dislocations

- Power and blocking voltage for valve stack

  Dielectric insulation / high-speed switching / HV packaging, press packs, cooling / thermal design, etc…

  HV passives integrated – at all levels (not necessarily monolithic)

  Reliability becomes a problem

- Efficiency (%, etc.)(on resistance)

  Power Efficiency of Components (>98%) vs. Energy Efficiency of System

- HV switches that could switch at higher speeds could get rid of transformers, but devices don't exist; ABB switching at 60Hz
- Congestion management – power electronics can play a role here as well
- We've done so little in passives; distributed controls technology is key area for development in future; need 30-year life in converters
- Not much diff b/t medium voltage DC and HVDC; materials are similar

What are the technical challenges for switched HVDC transmission and distribution?

- MV distribution (7.2kV – 33kV)
  - -Smart Grid: Congestion Management for T&D Deferral
- HV sub-transmission (33kV-115kV)
- HV transmission (115kV – 800kV): Dispatch variable wind across existing infrastructure (new research, enabled with power electronics)
- UHV transmission (800 kV and beyond): Topology design increases HVDC designs
  - Address DC Interruption Issues

4

Which technologies need to be developed for the near-term, mid-term, and long-term?

How can we integrate power electronics without degrading the 4 to 5 9's reliability on the grid

Materials bottleneck: Thick epilayer and Bipolar for SiC
Size of basic die – wafers with low defects for wide bandgaps

Thick epi-layers to achieve blocking voltage – 1C dislocations
Fault protection integrated as Switchgear in components (BILs, etc)
HPE: 100A/10kV/20kHz Modules (solid state power substation)

Module approach – series connection, self-protecting, balanced, and fault protection

- Bottlenecks at device level – making progress on materials; thick epilayer for SiC to support high voltage for blocking layer; bipolar devices need improvements in lifetime (more appropriate for materials discussion in afternoon)
- Size of basic die - wafers with low defects for wide bandgaps
- 100A/10kV/20kHz (solid state power substation) 1MW
- Dielectric insulation on high voltage, high-speed switching; other types of packaging that give longer lifetimes; high voltage (20kV) devices stacked together will create issues in fault management
- Fault protection; integrating switchgear into converter, BILs; integration brings cost down
- On the component level, we want to go to single switch solution; integrating passives with high voltage devices for dynamic voltage sharing is needed
- Module approach: series connection, self-protecting, balanced
- Integrating materials together is challenge; needs to be done at all levels

Technology Readiness Levels / Transformation

- Package and SiC Switch for 12.6kV Devices TRL not there to spur widespread investment or accelerated deployment
- Wind, Central station fuel cell, or Clean-Coal Plant – Eliminate step-up transformers to reduce cost of system to allow for higher device costs
- Higher power compressors for CO2
- DER/Storage Grid Integration PAP for 1587 for smart-grid as potential driver – pushing power across new grid capability
- Low Voltage Power Electronics - in process of adoption
- Medium Voltage to high voltage transformation
- BIL requirements for insulators and integration – different than low voltage requirements (example: bushing for HVDC)

arpa·e

- To be disruptive, define an application for this technology and then focus on it to advance technology; wind converters is one area to get rid of wire coming down the tower; convert to HV at the top of tower; get rid of weight as well (pay more for switch tech, but it gives you benefits in system; voltage levels ~2-6kV, would like to go to 13kV); GE is talking about SiC 12.6kV switches, but this is a technology issue
- Application #2: Get rid of step-up transformer at central station plant like clean coal plant or central fuel cell plant, reduces system costs (although device cost is higher); transformer-less systems is big potential win; get rid of large (low-frequency) 60Hz transformer and replace it with HV inverter (high frequency nanocrystalline)
- Power efficiency of components is another key metric (impacts efficiency of entire system)
- Capacitors and inductors matter too – not just semiconductors
- DC is key in some applications: Highly urbanized environments, undersea; where underground lines are required
- DC important for building new transmission to enable more renewable resources on the grid (10 years to get ROW for transmission lines); even harder since DC is currently point-to-point, so people on the way don't get benefit; we're not talking here about P2P transmission, must provide access to customers along transmission line so they benefit from electricity

What are the challenges and barriers for the validation and adoption of these technologies?

Policy issues that power electronics enable

Utility barriers to adoption – Why will they want to?

How can we show the utility can be more profitable through T&D deferral, etc…

“This is like changing from Railways to Highways, the railway company will not fund this”

Impact of CO2 – concern that fossil fleet obsolete / expensive (cap and Trade)

Enables Massive Integration of Renewable DG

Focus on Reliability as well as Profitability

Maintain and develop People who can install

- Regulatory issues: can have more efficient transformer, but doesn’t pass FERC rating; need policy and technology changes or utilities will not accept HVDC; don’t allow utilities to obstruct this technology; utilities will try to use existing technology to manage renewable integration, even as penetration increases to higher levels
- Stronger than energy efficiency; this technology enables massive amounts of distributed generation, which is key if cap and trade policy passes (medium voltage DC will be critical for DG); more renewables on grid, need to control where this electricity flows; power electronics play a critical role
- This is enabling technology for renewable integration; we can’t have renewables integrated into existing power grid without power electronics
- HVDC is like changing from railways to highways; railways won’t fund highway development
- Converters at every node – asynchronous; big change from current synchronous system (which is like rail)
- Utilities are concerned about CO2 emissions; this technology can help utilities mitigate risk of fossil assets becoming unusable (becoming expensive due to policy drivers like cap and trade)
- DoD is more receptive to using new technologies (DOD has mission, anything that helps mission is embraced); utilities are different, they are slow adopters of new innovations, and this is a critical issue
- Utilities worry about reliability – ARPA-E will need to show utilities that this tech can be installed and operated predictably and reliably; maintainability is important, people must be educated to keep new tech in operation

- Discussion about role of ARPA-E vs. OE; some degree of reliability must be shown early on for technology. How to integrate power electronics without degrading current levels of reliability?
- Resistance from society may occur as well if there are accidents with HVDC
- Renewable integration is key, using power converters already; could ultimately change grid, not just integrate with it
- Need distributed power conversion solutions
- Utilites: care about price, maintainability,

What level of investment would be required to develop and deploy these technologies? What is the return on investment?

Two pronged approach:

- Explorational Component for New Looks at Problem
- Moving the ball forward on long range roadmap (de-risking until industry adopts)

- Interagency Advanced Power Group:
  1C Screw Dislocations
- An ARPA-E-Net test bed: leverage recent advances in other areas
- Broader MV-HV Power Conversions Technologies-
  - Insulation, Packaging, Device, Switches
  - Marginal gains in efficiency for near term

8

- Move toward higher voltage, higher frequency devices; need investment for “ARPA-E net”; demo of future grid, testbed;
- Transformation of system needs, then focus on enabling technology
- Two paths forward:
  - Incremental advances in tech that is almost ready, volumes increase, costs come down
  - Transformational advances that lead to breakthroughs in cost (ARPA-E)
- Does smart grid investment open up new opportunities for HV power electronics? MW-scale inverters for grid-scale storage; current effort is AMI and substation automation; ISOs main concern above 5-8% is grid stability
- Power electronics has focused on low voltage apps; can we do what we’ve done there in medium voltage, and then in high voltage?

- BUT, high voltage requires different requirements: insulation, BIL, spacing; Scalability can be issue when you scale to high voltages – spacing requirements; UHV requires different form factors, materials (like Le’s bushing example in the morning)