Fiber Optic Technology Will Drive Next Generation Intelligent Substations

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Elements of the Intelligent Substation

**Optical Transducer**
- Current/voltage data from Non-Conventional Instrument Transformer
- Analog or digital format

**Merging Unit**
- Signal conditioning and A/D conversion, if necessary
- Synchronization and packet dating
- Conversion of proprietary data stream to standardized IEC 61850-9-2 packet format

**LAN Switch**
- Dynamic routing of data

**Intelligent Electronic Device**
- Data processing, decision-making, initiation of action (e.g., operate relay, trip breaker)
- Peer-to-peer message to other IEDs to initiate control action

Synchronized, dated, packetized data samples transmitted over fiber optic cables

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**Traditional Substation**
- Electromechanical relays, programmable logic controllers and microprocessors
- Master–slave protocols
- Copper wire interfaces

**Intelligent Substation**
- Digital input from optical transducer; Ethernet communications between interchangeable IEDs
- Peer-to-peer messages over process bus
- Small numbers of fiber optic cables replace large bundles of copper wire
Why Use Optical Transducers?

Conventional Instrument Transformer

- Proven
- Heavy and challenging to install at higher voltages
- Subject to open current circuit conditions
- Potential for explosion or leak
- Must convert analog measurement to digital format in intelligent substations

Non-Conventional Optical Transducer

- Unaffected by high voltage, lightning or electromagnetic effects
- Small size conserves substation space and reduces seismic considerations
- Not subject to open circuit conditions
- Dry signal column eliminates possibility of explosion or leak
- Compatible with IEC 61850–9.2 digital process bus requirements

Source: Siemens Power Technologies, Areva T&D
# Optical Measurement Technologies

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Optical Current/Voltage Sensors</th>
<th>All-Optical Transducers</th>
<th>Electro-Optical (Digital) Transducers</th>
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<tbody>
<tr>
<td><strong>Application</strong></td>
<td>• Current and voltage sensing on LV and MV AC Networks (up to 36 kVAC)</td>
<td>• Current and voltage sensing on HVAC and HVDC Networks (100 kV to 550 kV)</td>
<td>• Current sensing on HVAC and HVDC Networks (100 kV to 800 kV+)</td>
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<tr>
<td></td>
<td>• Primarily in distribution networks</td>
<td>• Primarily in substations</td>
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<tr>
<td><strong>Measurement Technology</strong></td>
<td>• Non-conductive Faraday Effect sensors and fiber cable</td>
<td>• Optical light source illuminates Faraday Effect sensors, photodiode measures intensity and rotation of polarized beam and converts it to analog signal</td>
<td>• Optical light source illuminates photovoltaic conversion device to generate electrical power</td>
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<td>• Measured current is converted to digital format on the HV line and sent optically to the control room</td>
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<td><strong>Typical Current Measurement Performance</strong></td>
<td>• Current range 5–20,000 AAC</td>
<td>• &lt;0.2% metering accuracy from 1A to 5000A</td>
<td>• &lt;0.1% metering accuracy from 1A to 1500A, and &lt;0.2% from 1500A to 5000A</td>
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<td>• +/-2A accuracy (5–100A)</td>
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<td>• 2% accuracy (100A–20,000A)</td>
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<td><strong>Advantages</strong></td>
<td>• Simple, inexpensive system and installation</td>
<td>• Wide dynamic range for protection, and good measurement accuracy for metering</td>
<td>• Metering, protection and temperature measurement in one system</td>
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<td>• Non-conductive materials allow installation on cables or copper bars</td>
<td>• Fully optical solution using one fiber</td>
<td>• Electronics optically isolated from HV lines by non-conductive fiber</td>
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<td>• 18-bit digital measurement accuracy</td>
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<tr>
<td><strong>Disadvantages</strong></td>
<td>• Measurement accuracy insufficient for 100 kV and above</td>
<td>• Precise installation of optical sensor required to avoid environmental or temperature effects</td>
<td>• Requires power fiber and data fiber</td>
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</tbody>
</table>
Electro–Optical Transducer System Approach

- **Application**: Current metering and protection and temperature measurement on HVDC or HVAC line
- **Enabling Technology**: Optical–to–electrical power conversion; analog signals converted to digital format on HV line and transmitted to control room via fiber optic line (or optionally over a wireless connection)
- **Key Benefit**: Non-conductive nature of fiber optic power cable isolates the electronics from ground permitting measurement electronics to mount in close proximity to the high voltage line

Source: JDSU Corporation
Enabling Technology: Power by Laser Light

- Single junction AlGaAs or InP semiconductor device converts laser light to electrical power with 40%+ efficiency.
- Voltage from each segment of device added in series; delivered electrical current is linearly proportional to input optical power level.
- 6-segment device below delivers about 220mW of electrical power.
- Same functionality as solar cell, but optimized for maximum efficiency over the wavelength range of the laser source.

Source: JDSU Corporation
Power by Light Block Diagram (All–Fiber Solution)

- Fiber Solution
- Source: JDSU Corporation

**Power by Light Block Diagram:**

- **Power by Light Block Diagram:**
- **Source:** JDSU Corporation

**Key Components:**
- **PPC (2-12 VDC):**
  - LED Signal Transmitter
  - Laser Diode
  - Laser Diode and Driver
- **Signal Receiver**
- **Network Control**
- **Merging Unit**

**Diagram Details:**
- Multimode data fiber delivers optically modulated digital data stream to merging unit in control room.
- Optically-powered remote module processes up to 7 metering, protection, and temperature channels simultaneously.
- Up to 500m of multimode fiber delivers laser light to Photovoltaic Power Converter (PPC).

**Contextual Notes:**
- Current Metering
- Current Protection (4)
- Temperature (2)
- Rack-mountable local module monitors laser output power, data link integrity, and synchronization.
Power by Light Block Diagram (Fiber/Wireless Solution)

- **Current Metering**
  - Analog Sensors or Rogowski Coil
  - Power
  - Analog to Digital Converter

- **Power by Light Converter (PPC)**
  - (2-12 VDC)
  - Wireless Protocol
  - RF Transmitter

- **Network Control**
  - Merging Unit
  - RF Receiver
  - Laser Diode and Driver

- **Up to 500m of multimode fiber delivers laser light to Photovoltaic Power Converter (PPC)**

**Optically-powered remote module**
- processes up to 7 metering, protection, and temperature channels simultaneously

- **RF link, fully isolated from high voltage line, replaces data fiber**

- **Rack-mountable local module monitors laser output power, data link integrity and synchronization**
Intermountain Power Generator Station, Utah

- Intermountain is using an optically-enabled CT system for power metering and protection of its 490-mile transmission line
- Grid is reliably serving nearly four million homes in Arizona and Southern California

Optically-powered Remote Module powers the measurement electronics

Optical CT System converts 3200 Amps of current at 500kVDC to digital data stream for metering and protection

490-mile long HVDC transmission line delivers 1600MW to Arizona and California

Source: JDSU Corporation
China is Leader in Electro-Optical Transducer Deployments

- Several HVDC ECT systems are operational in China
  - Monitoring HVDC lines carrying 1000MW to 6000MW of power over distances ranging from 500 to 1400 km
  - Several more HVDC ECT projects underway

- HVAC ECT systems being certified and field tested in China at 110kV to 550kV; higher voltages under evaluation

Source: Siemens Power Technologies
Enabling the Intelligent Substation with Fiber Optics

Performance Benefits

- Precise measurement and synchronization
- Better protection against current surges and open circuit conditions
- Enables digital substation process bus per IEC61850–9.2
- Impervious to electromagnetic effects, high voltages, and lightning

Operational Benefits

- Potential to reduce outage minutes
- Potential to allow grid to be run closer to rated capacity
- Accurate time history of events in digital format
- Eliminates potential for transformer leaks or explosion

Improved accuracy, control, response, and safety
Summary

- Fiber optic technology can be a key enabler for the Intelligent Substation.
- Moving from analog to digital grid control offers benefits in performance, operation, safety and O&M.
- The technology to deploy the electro–optical transducer exists and has been deployed in many HVDC applications worldwide.
- China has served as the first proving ground for electro–optical transducers for HVAC applications.
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- Perform technology assessment and validation
- Manage due diligence

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