ELG4126
Smart Grid Technologies

Technologies

Challenges

Wind Farms

Photovoltaic System

Three Questions to Answer!

Why smart grids will be necessary?

How smart grids work?

Why there’s an initial focus on smart meters?

What is the Scale of Market Opportunities?

Definition and Benefits

- The term “Smart Grid” refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.
- The Smart Grid will be characterized by a two-way flow of electricity and information to create an automated, widely distributed energy delivery network.
- The smart grid incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level.

Based on the USA Energy Independence and Security Act of 2007

Schematic of the Smart Grid

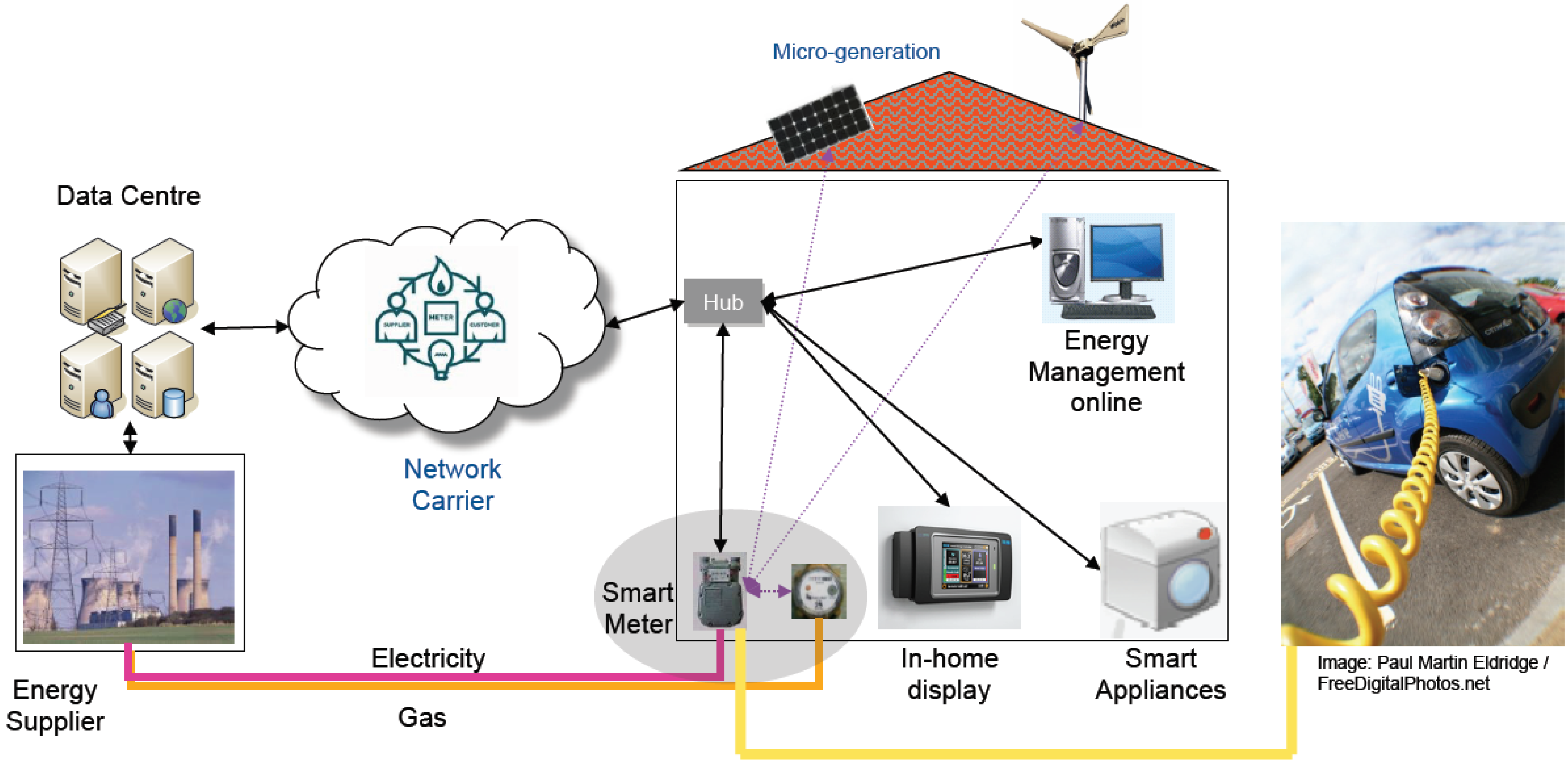


Image: Paul Martin Eldridge / FreeDigitalPhotos.net

What to Learn about the Smart Grid

- Phasor measurements and their utilization in power systems for improved monitoring, protection, and control.
- The role of digital relaying in new protective relaying, monitoring, control, power quality and asset management applications.
- Special protection schemes and their role in detecting, mitigating and preventing cascading outages.
- Impact of Plug-In Hybrid Electric Vehicles (PHEVs) and Electric Battery vehicles (EBVs) on electricity and transportation infrastructure.
- Multifunctional uses of smart meters for revenue metering, demand side management, outage management, and load control
- Integration of AC and DC systems in creating new micro grid solutions for residential and industrial applications
- Energy efficiency and the technologies that allow implementation of highly efficient and yet economical, affordable solutions for the Smart Grid

Integration Complexity

- Integration of renewable resources (wind, solar, geothermal, etc.) into the grid.
- Integration of data from different substation Intelligent Electronic Devices (IEDs) in substations.
- Integration of various communication solutions for selected applications such as automated metering.
- Integration of environmentally friendly solutions with legacy solutions.
- Integration of the load as a resource solution with traditional passive load solution.
- Integration of micro grids and PHEV/EBV solutions with the backbone grid.

The Smart Meter

Two way communications.

Interval measurement and storage of consumption data.

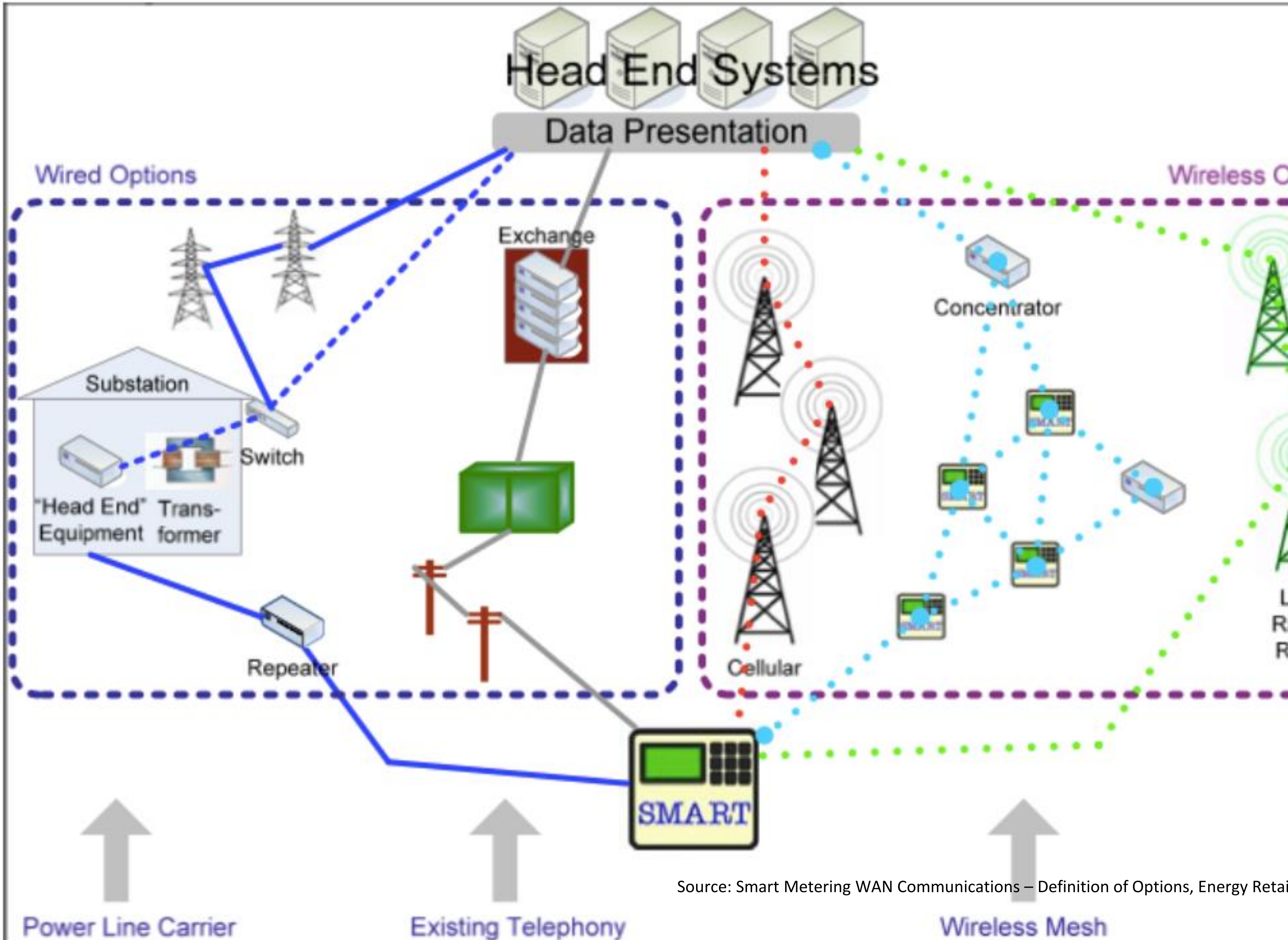
Display of consumption data to consumer.

Remote connection/disconnection.

Support for variable energy tariffs.

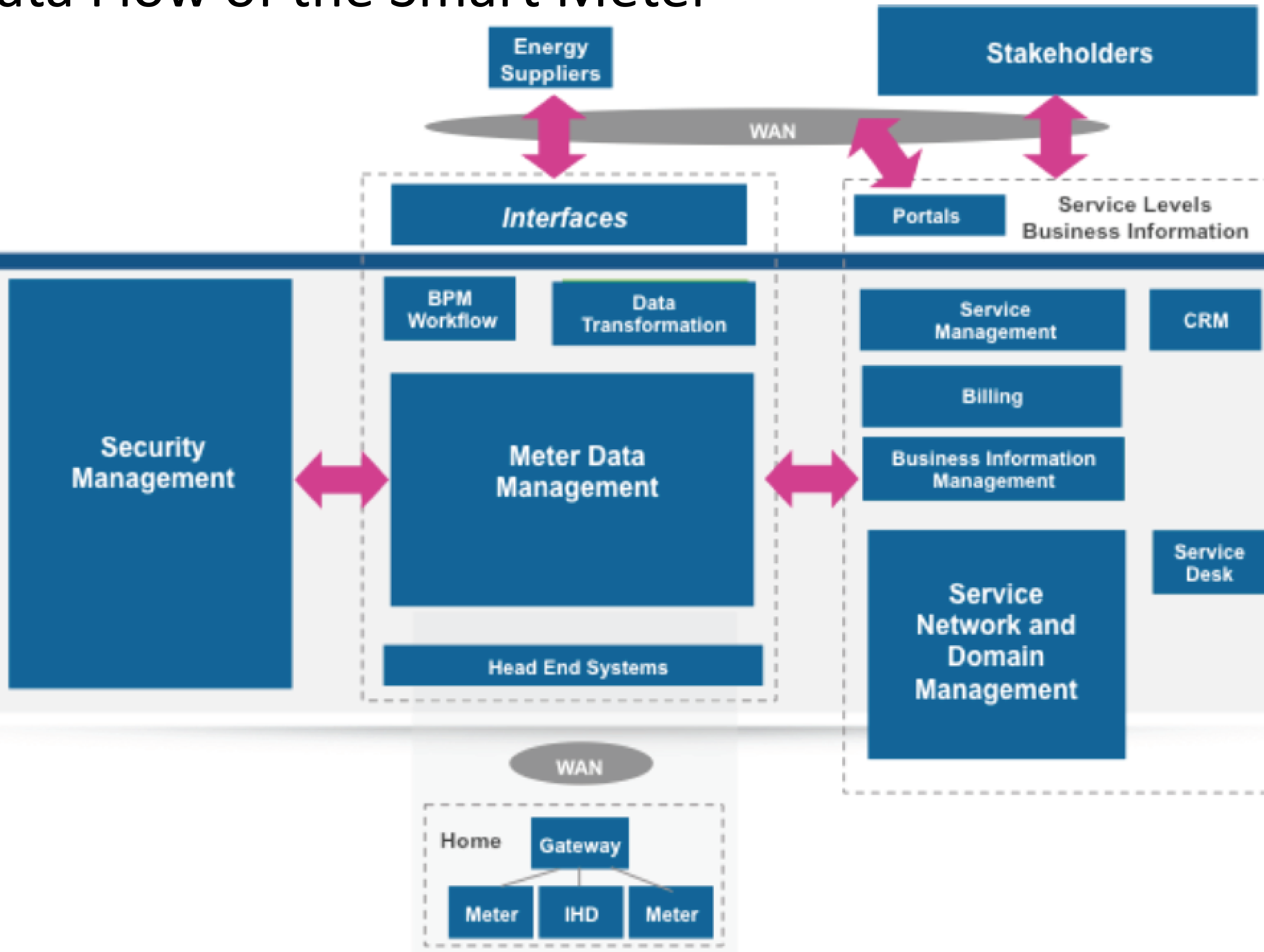
Support for micro-generation.

Demand control.



Source: Smart Metering WAN Communications – Definition of Options, Energy Retai

Data Flow of the Smart Meter



Communication Technologies

- There are several communication options available for the grid integration of renewable energy resources. These options include a hybrid mix of technologies, such as
- Fiber optics
- Copper-wire line
- Power line communications, and
- A variety of wireless technologies.

Challenges!

- There is currently ongoing debate surrounding what will emerge as the communications standard of choice. Since utilities want to run as many applications as possible over their networks, issues of
  - Bandwidth
  - Latency
  - Reliability
  - Security
  - Scalability
  - Cost
- In addition, distinct characteristics in electric grid pose new challenges to the communication systems for grid integration of renewable energy resources.

Typical Communication System

- A typical electric grid communication system consists of:
  - High-bandwidth backbone.
  - Lower-bandwidth access networks, connecting individual facilities to the backbone.
- Technologies for the backbone include
  - Fiber optics and/or
  - Digital microwave radio.
- The access may use alternatives such as
  - Copper twisted-pair wire lines.
  - Power line communications.
  - Wireless systems.

Power Line communications

- Power line communications (PLCs) are to use existing electrical wires to transport data.
- New PLC technologies are available that allow high bit rates of up to 200 Mb/s.
- PLC can be used in several important applications: broadband Internet access, indoor wired local area networks, utility metering and control, real-time pricing, distributed energy generation, etc.
- From a standardization point of view, competing organizations have developed specifications, including HomePlug Powerline Alliance, Universal Powerline Association and HD-PLC. ITU-T adopted Recommendation G.hn/G.9960 as a standard for high-speed power line communications.
- In IEEE, P1901 is a working group developing PLC medium access control and physical layer specifications.
- National Institute of Standards and Technology (NIST) has included HomePlug, ITU-T G.hn and IEEE 1901 as “Additional Standards Identified by NIST Subject to Further Review” for the smart grid in the USA

Wireless Home (Local) Area Networks

- A leading standard for the wireless home network communications is ZigBee. The Zigbee Smart Energy standard builds on top of the ZigBee Home Automation (HAN) standard. HAN provides a framework to automatically control lighting, appliances, and other devices at home.
- ZigBee Smart Energy provides a framework to connect HAN devices with smart meters and other such devices. This will enable the energy utility to directly communicate with the end consumers of energy.
- Wi-Fi is often used as a synonym for IEEE 802.11 wireless local area network (WLAN) technologies. Wi-Fi became a standard for laptops and subsequently phones due to its high data rate. When using it in utilities, however, Wi-Fi's power consumption is an issue that needs to be considered carefully.
- The ZigBee Alliance and the Wi-Fi Alliance are collaborating on applications for energy management and networking. The goal will be to get Smart Energy 2.0, a standard promoted by ZigBee, to work on Wi-Fi.

Wi-Fi

- **Wi-Fi** is a wireless network that uses RF energy similar to that of cellular systems but at considerably higher frequencies. Wi-Fi is based on the IEEE 802.11 networking standards that specify an “over-the-air” interface between a wireless client card (located in computers) and access points (typically located in the ceiling of public areas with hotspots), as well as among wireless clients.
- The IEEE 802.11 standard comes in several versions. 802.11a transmits in the 5 GHz frequency band and may handle up to 54 Mbps of data. It employs orthogonal frequency-division multiplexing (OFDM), an efficient coding technique that splits RF signal into several sub-signals before they reach a receiver. This significantly reduces interference.
- 802.11b transmits in the 2.4 GHz frequency band. It can handle up to 11 Mbps of data and it uses complimentary code keying (CCK) technique. 802.11g transmits at 2.4 GHz also but it can handle up to 54 Mbps of data. 802.11g is faster because it uses the OFDM coding as 802.11a. 802.11n is the newest standard that improves the speed to as high as 140 Mbps.

WiMax

- **WiMAX** is a worldwide certification addressing interoperability across two major versions of the IEEE 802.16 standards-based products: IEEE 802.16d (802.16-2004) and IEEE 802.16e.
- The IEEE 802.16d standard is mainly designed for outdoor fixed wireless access in which antennas of base stations and subscriber stations are mounted to roofs or masts for signal transmissions and receptions.
- The IEEE 802.16e standard is an amendment to the IEEE 802.16d and aims to provide service providers the capacity to offer a wide range of high-speed mobile wireless applications and services.

Ultra Wide Band (UWB)

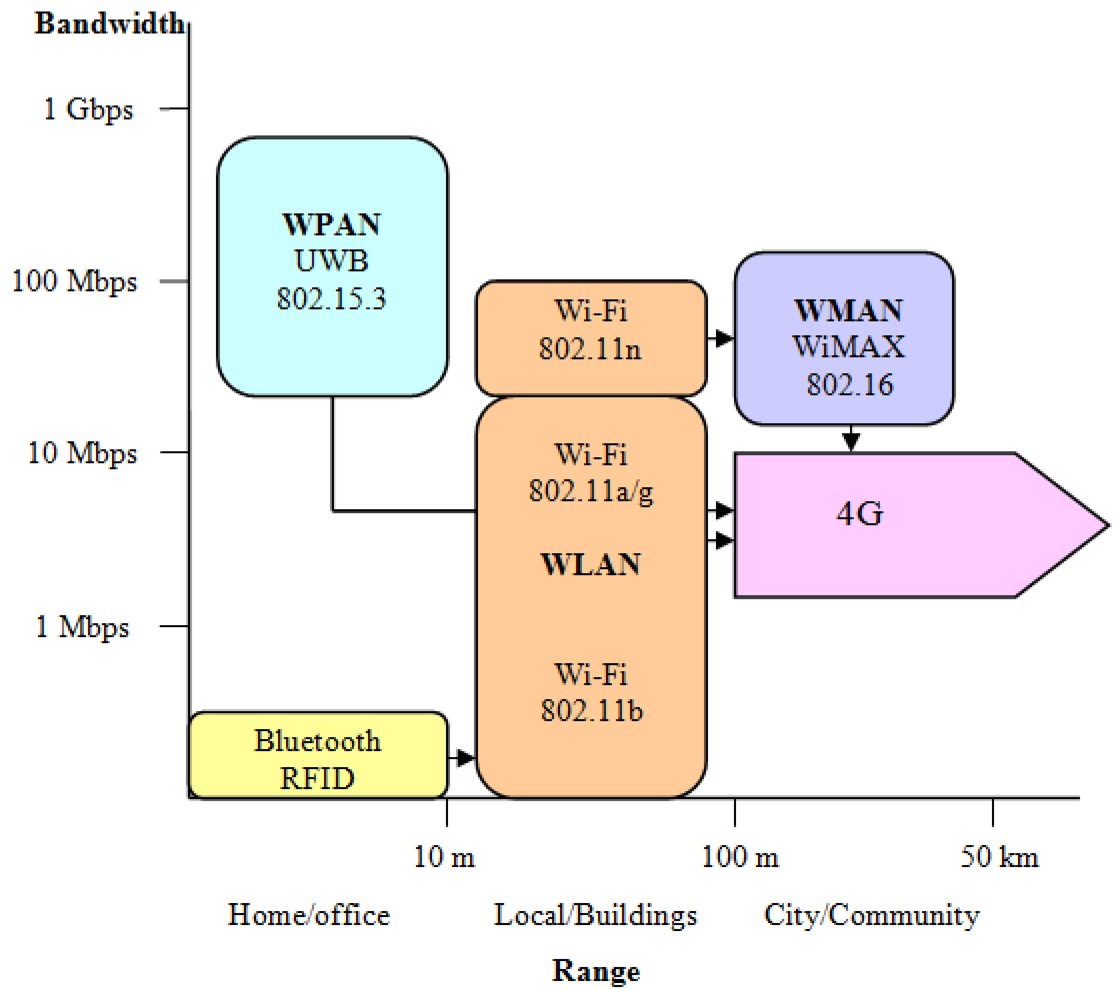
- This IEEE 802.15-based technology brings the convenience and mobility of wireless communications to next-generation consumer electronic devices.
- UWB offers a solution for the high bandwidth, low power consumption, low complexity and cost, and physical size requirements of digital home and office. It is the emerging technology for freeing people from wires and enabling wireless connection of multiple devices for transmission of multimedia services.
- UWB supports wireless connectivity with consistent high data rates (greater than 100 Mbps within 10 m radius) across multiple devices and personal computers (PCs) within homes and offices.
- UWB operates in the frequency range of 3.1-10.6 GHz at a limited transmit power of -41dBm/MHz.
- UWB complements WiFi and WiMax and cellular wide area communications. Although data rates can reach 54 Mbps for Wi-Fi, for example, the technology has limitations in a consumer electronics environment, including power consumption and bandwidth.

Wireless Wide Area Network

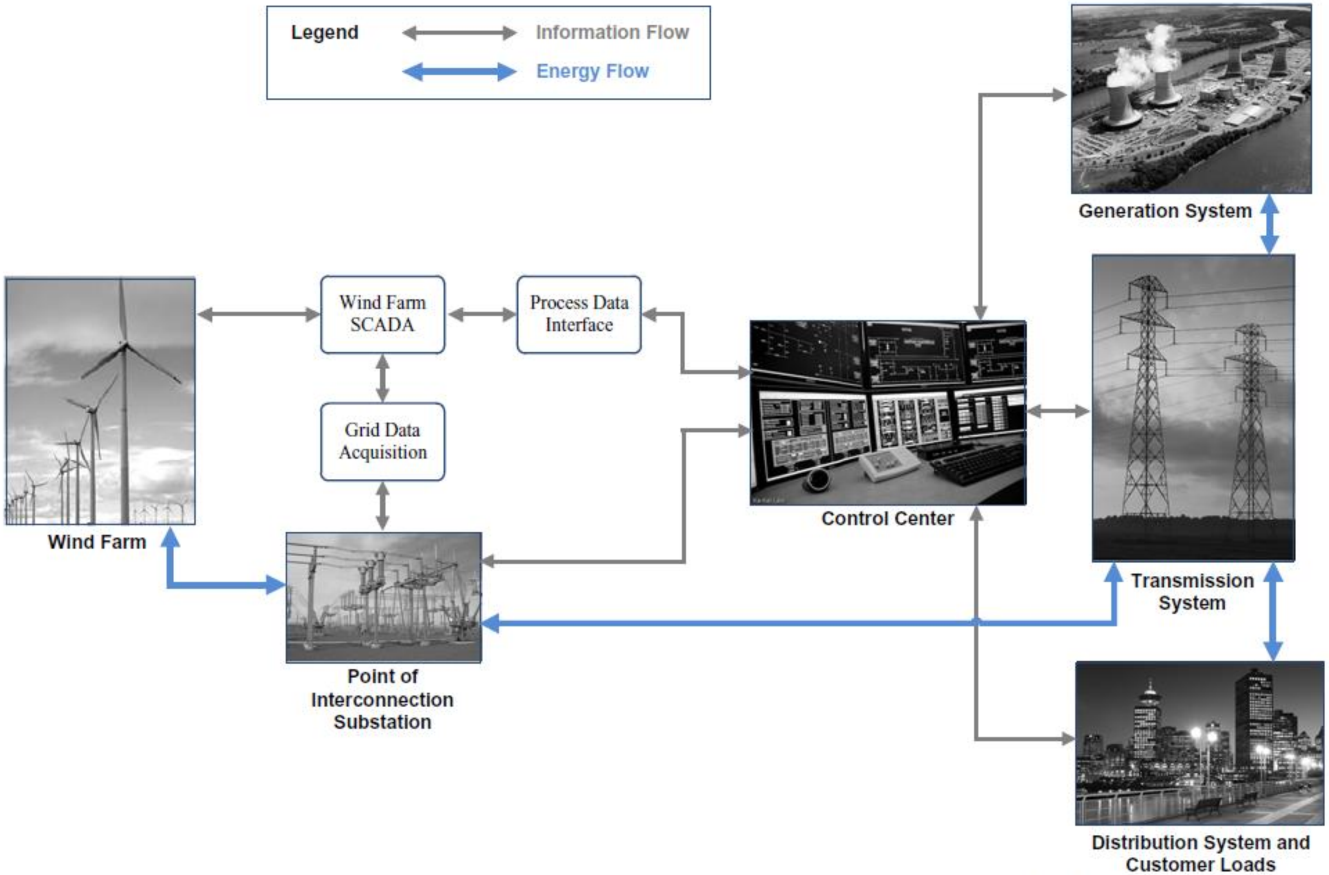
- WiMAX is based on the IEEE 802.16 standard, enabling the delivery of wireless broadband communications.
- Unlike the now-popular wireless networking technologies using unlicensed spectrum.
- WiMAX uses licensed wireless spectrum, which is arguably both more secure and reliable. The primary disadvantage of using a licensed network is that it is more expensive.
- In addition, compared to cellular technologies, WiMAX has yet to be deployed at scale, which means some risks when applied to utilities.

Wireless Technologies

	Wi-Fi	WiMAX	UWB	Bluetooth	RFID
Standard	IEEE 802.11	IEEE 802.16	IEEE 802.15	IEEE 802.15.1	ISO15693; SIP; ISO18000
Frequency	2.4 and 5 GHz	Above 11 GHz	3-10 GHz	2.4 GHz	13.65/800/900/ 2400 MHz
Modulation	OFDM; CCK; QPSK; QAM	OFDM; QPSK; QAM	OFDM; QPSK; QAM; PPM; AM	GFSK	ASK/FSK/PSK
Power	100 mW	Client: 100 mW-2W; Base: ~100W	-0.08 μW/MHz	1-10 mW	0.1-2 W
Range	Up to 100m	1-50 km	Up to 10m	Up to100m	Up to 10m
Application	Radio interface	Multimedia traffic	Multimedia services	Cable replacement	Identification and tracking


Bandwidth
1 Gbps
100 Mbps
10 Mbps
1 Mbps
WPAN
UWB
802.15.3
Wi-Fi
802.11n
WMAN
WiMAX
802.16
Wi-Fi
802.11a/g
WLAN
Wi-Fi
802.11b
4G
Bluetooth
RFID
10 m
100 m
50 km
Home/office
Local/Buildings
City/Community
Range

Communication Technologies *for* Grid Connected Wind Farms



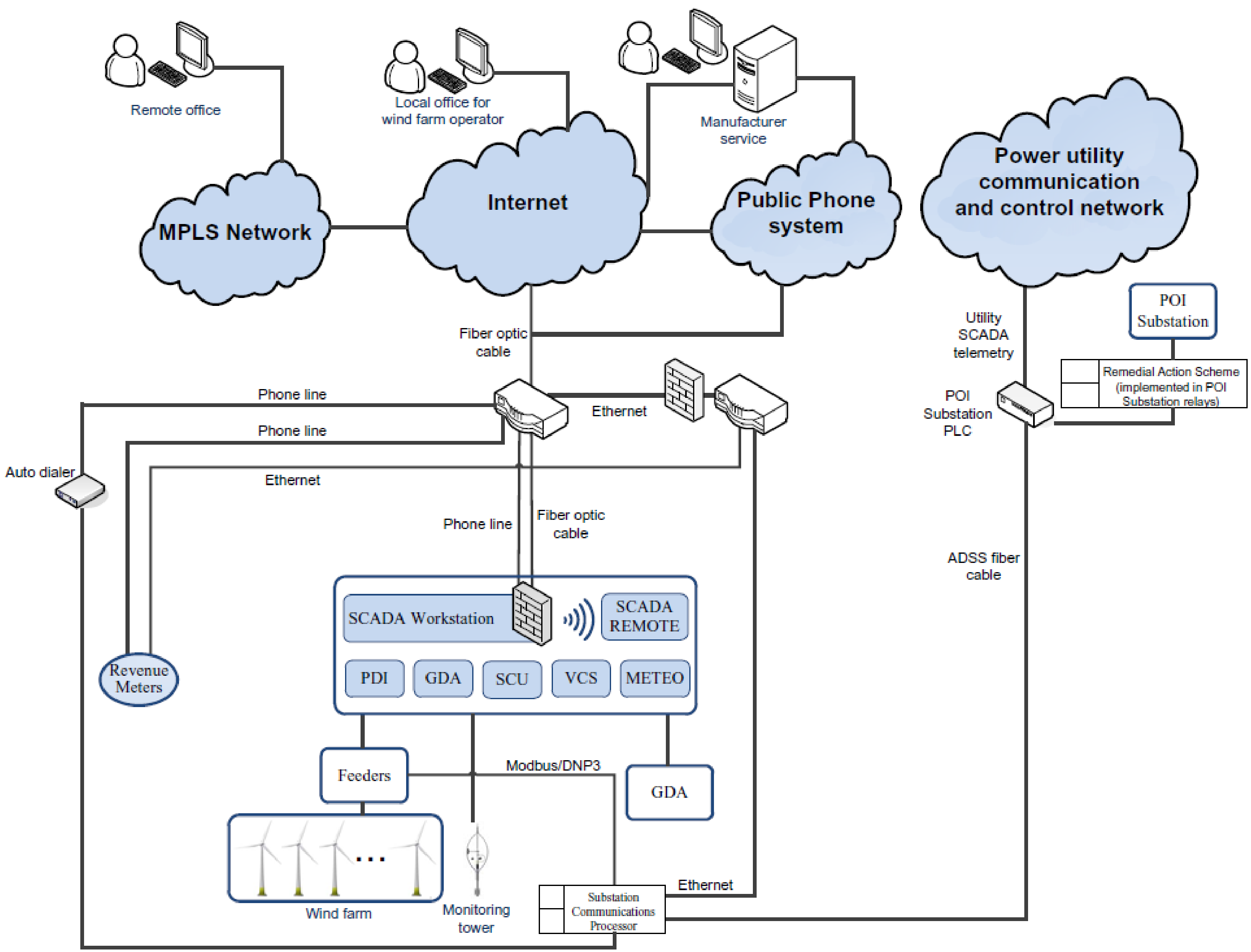
Grid integration of a wind farm. (Photo courtesy of BC Hydro)

Richard et al., Communication Systems for Grid Integration of Renewable Energy Resources

The SCADA System

- SCADA system is used for data acquisition, remote monitoring, open-loop and closed-loop control for both individual wind turbines and the whole farm.
- SCADA also provides a platform for the customer, the manufacturer of the wind turbines, and the utility to access the operating state and to analyze sampled event data.
- Authorized users can use the SCADA to modify parameters of wind turbine controllers and voltage control system (VCS).
- This feature is of special importance because wind farm controllers need to be tuned to achieve optimized performances under varying power system conditions.
- The closed-loop control to regulate the voltage at Point of Interconnection (POI) is another desired SCADA feature, which coordinates wind turbine outputs and provides reactive power support for utility system.

SCADA System in a Wind Farm



Richard et al., Communication Systems for Grid Integration of Renewable Energy Resources

SCADA Functions

- SCADA REMOTE: Used for remote monitoring of wind farm data. Authorized users may access SCADA database and modify controller parameters.
- PDI (Process Data Interface): Used for exchanging real time wind farm data with external communication systems.
- GDA (Grid Data Acquisition): Used to measure electrical variables at the point of interconnection.
- SCU (Substation Control Unit): Used for monitoring electrical states and for remote switching operation within the substation of wind farm.
- VCS (Voltage Control System): Used for controlling the dynamic voltage at the point of interconnection by utilizing reactive power capability of wind turbines online.
- METEO: Used for collecting meteorological data such as wind speed, wind direction, temperature, etc.

The SCADA System

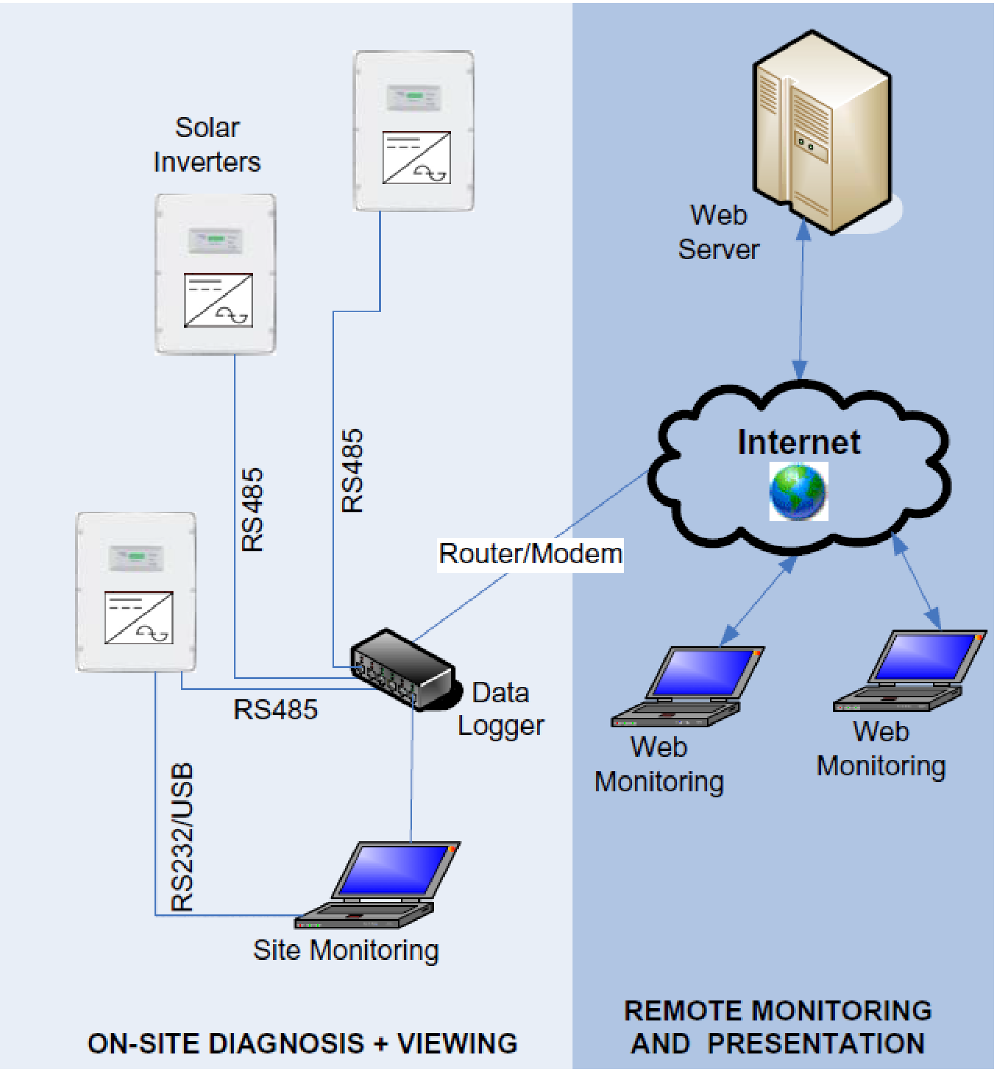
- The status data and measured data transmitted by SCADA using standard formats such as OPC XML-DA, or IEC 60870-5-101(or 104), etc.
- BMW SCADA cyclically queries the operating and status data from wind turbines via the data bus.
- The SCADA calculates the average values over 10-minute, day, week, month and year periods, together with minimum and maximum values.
- Status data is updated up to four times per second. The internal data bus system normally uses fiber optical cables to guarantee the communication speed.

Communication Technologies for Grid-Connected Photovoltaic System

- Grid-connected solar systems are typically classified as three categories: residential, commercial, and utility scales.
- Residential scale is the smallest type of installation and refers to all installations less than 10 kW usually found on private properties.
- The commercial capacity ranges from 10 kW to 100 kW, which are commonly found on the roof of a commercial building.
- Utility scale is designed to the installations above 100 kW, which are traditionally ground-based installations on fields (also known as solar farms or plants).

Monitoring Application of Grid-Connected Photovoltaic System

These systems normally monitor the following variables: the solar array power production, inverter output, inverter status, AC grid conditions, weather station data, temperature of key components, and solar irradiance, etc. The owners or operators can follow the real-time details about the system operation.



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Monitoring on All Levels

- A recent development is to integrate communication systems into the photovoltaic panel, to sense the voltage, current and temperature of each module, and send the information data to the monitoring interface.
- The solar power monitoring can be classified as three categories: system level, string-level, and module-level. The system monitors the status of solar modules, solar strings, and solar inverters based on the IEEE 802.15.4-2003 ZigBee standard.
- With this wireless monitoring capability, each solar module status is visible. In practical systems, this is very useful because most solar panels are installed in the areas that are not readily accessible. Otherwise, the troubleshooting of solar modules is very difficult.

Research Challenges

- **Power consumption of the end device:** Developing an energy efficient communication network for solar power integration will significantly reduce the life cycle cost of solar projects.
- **Reliability, coverage, and flexibility:** The trade-off among power consumption, reliability, coverage, throughput, latency, etc. merit further investigation for the wireless communications used in photovoltaic power systems.
- **Addressing and localization:** A solar power system consists of many photovoltaic panels, which are vulnerable to failures and have high maintenance demands. How to identify the failed panel quickly is an interesting research topic.
- **Islanding detection:** Photovoltaic power systems face the same challenge of island detection as wind power systems do. Using wireless communications or PLC could be a fast and accurate means for island detection and control in photovoltaic power systems.