CHAPTER

SCADA and smart energy grid control automation

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18.1 INTRODUCTION

In this chapter, supervisory control and data acquisition (SCADA) systems for a smart power grid are explained, with discussion about the efficacy and challenges in the integration process and the automation systems. The smart grid SCADA system integrates the existing renewable energy sources (RES) system with digital information processing and advanced telemetry systems. It is clear that the increased integration and automation of the electric microgrid and utility grids present new development aspects of energy management. Automation systems are computer-based control systems used to control and monitor sensitive processes within various industries and critical infrastructures such as electric grid, energy grids, natural gas pipelines, water pipelines, and wastewater industries. The SCADA control systems might perform additional automation functions such as switching circuit breakers (CB), adjusting protection relays settings, operating switches, and adjusting flow valves to regulate the fuel flow [1–4]. Typically, control systems collect site measurement and operational data from the electric substation, and then process, display, and analyze this information. The remote control commands to local or remote outstations are issued from the master station control center.

Using control systems in power system applications has become increasingly attractive during the past few decades. There are two major types of control systems: SCADA systems and distributed control systems (DCS). Typically, DCS systems are used within one generating station or over a specified geographic zone. SCADA systems usually are used for electricity transmission extended geographically over long distances or radial distribution. Utilities, however, might use a DCS in traditional power generation stations and an SCADA system in transmission and distribution substations, although SCADA also is applicable in large-scale renewable energy systems, such as wind and solar farms. SCADA systems for renewable energy are computer-aided control systems, sometimes called renewable energy management systems (EMS).

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EMS have become more advanced recently because of the intelligence and high capabilities of the applications software. The requirements for data acquisition electronic devices and the associated communications systems within the control center were extended to the limits that computer and communication technologies could offer at the time. Specially designed systems and devices had to be developed to fulfill the power system application requirements taking advantage of advanced information and new communication technologies. Recent trends in control industry deregulation have changed the requirements of the electricity supervisory control center and have uncovered its weakness. In the past, conventional control centers were inflexible, independent, too centralized, and closed by today's standards. The evolving changes in recent power system operational needs demand a distributed control center that is decentralized, flexible, integrated, and opened. Today's control centers are moving in that direction with varying degrees of success [5–10].

As the backbone of large-scale renewable power SCADA systems should have all of the design elements to accommodate the multifaceted nature of distribution automation and the distribution management system (DMS) applications. A smart grid SCADA system's main function is to assist distributed generation, switching procedure, alarming, telemetry, event logging, measurement recording, and remote control of outstation equipment.

A modern SCADA system should support the engineering plan by providing entrance to power system data without affecting any operational workstation. SCADA systems are known for their effective support for exporting power system network data, and we will review briefly the SCADA technologies utilized in today's control centers to enable them to be more distributed. With the rising of the Internet age, the trend in information and communication technologies is moving toward microgrid and grid computing and Web services, or microgrid services, and so a microgrid service-based future control center will be needed.

Renewable energy systems have gained more popularity over the years because of the incessant failure and general unreliability of the power grids and microgrids. Renewable energy forms a major source of energy in distributed generation systems; the energy generated can be integrated into the existing power grid or it can be used for domestic microgrid consumption. Even though renewable sources are in abundance and inexhaustible, their occurrence at a quantity enough for power generation at all times is not guaranteed because of variations in climatic conditions, thereby jeopardizing the chances of relying on them as the only source of energy. This prompted research and development in the areas of power generation and storage of energy in order to improve the efficiency of such systems. Such research has led to a drastic reduction in the cost of these systems, which convert renewable energy into electrical energy.

The increasing size of photovoltaic (PV) power plants all over the world has made their operation and maintenance tasks much more complex than they were a few years ago [10]. Many of these PV plants are equipped with advanced SCADA systems in order to collect the necessary information to assess their performance, such as meteorological data, information from the PV farm field, and PV inverters [11–14].

The great amount of data provided by those SCADA systems, however, requires the development of new procedures capable of handling all this data and providing accurate information about the performance, failures, and long-term trends. Little information is available today about experiences in automatic failures detection and performance evaluation of large-scale solar PV plants.

SCADA systems are essentially process control systems (PCS) that gather, monitor, and analyze real-time environmental data from a simple residential building or a complex large-scale PV or wind farm power plant. PCSs are designed for microgrid automation or power distribution systems based on a predetermined set of data and conditions, such as generated/consumed energy or power grid management. Some systems consist of one or more types of data acquisition devices such as remote terminal units (RTUs) and/or programmable logic controllers (PLC) that are connected to any number of field devices such as sensors, digital meters, protection relays, and station alarms (batteries, chargers and fire alarm).

SCADA systems are composed of the following equipment:

1. *Outstation hardware*: Remote substation control devices, such as state of charge, current transformer (CT), voltage transformer (VT), fuel valves, and CB that can be controlled locally or remotely.
2. *Local substation processors*: Collect data from the field instruments and hardware equipment, including the RTU, PLC and intelligent electronic devices (IEDs), such as digital relays and digital meters. The local processor is responsible for dozens of analog and digital inputs/outputs from IEDs and switchgear equipment.
3. Digital instruments: Usually installed in the field or in a facility and sense conditions such as current, voltage, irradiance, temperature, pressure, wind speed, and flow rate.
4. Communications devices: Could be either short-range or long-range communications. Short-range communications are installed between local RTUs, instruments, and operating equipment. These are relatively short distance cables or wireless connections that carry digital and analog signals using electrical properties, such as voltage and current, or other settled industrial communications protocols. Long-range communications are installed between local processors RTU/PLC and host servers. This communication typically uses methods such as leased telephone lines, microwave, satellite, frame relay network, and cellular packet data.
5. Host computers/servers: Host computers, such as data acquisition computer server, engineering/operation workstations. As the central point of monitoring and control, they will be in the control room or master station. The operation workstation is where an engineer or operator can supervise the process, as well as receive system alarms, review data, and exercise remote control.

Fig. 1 displays a high-level overview of SCADA architecture, where the remote stations might be an electric substation, the SCADA network on one segment, with another organization network on differing network segments. With the progress in

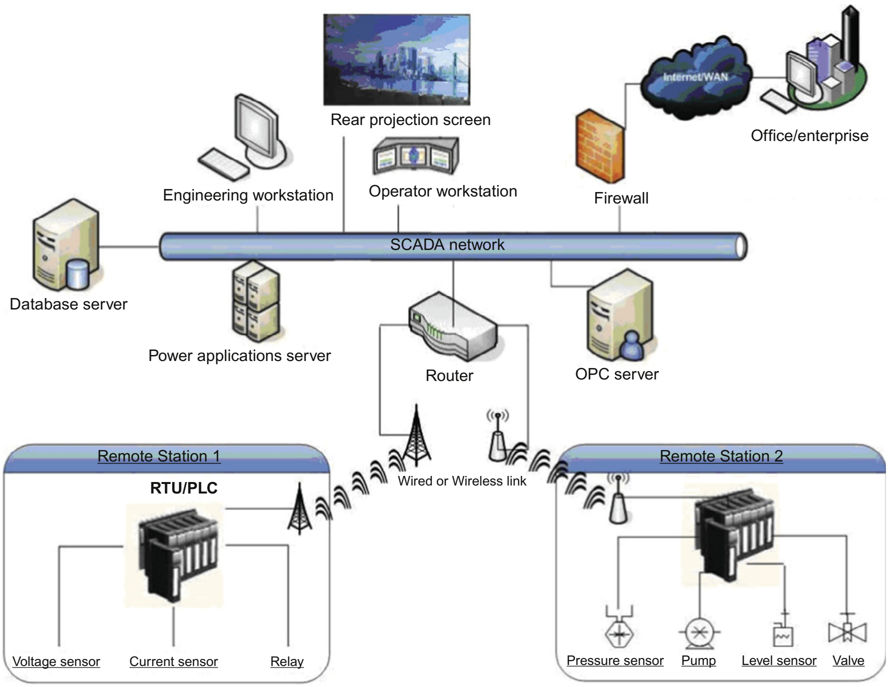

FIG. 1

SCADA system network.

digital computing, the integration of digital IEDs plays a substantial role in industrial manufacturing, wherein a factory uses PLCs/RTUs to control the devices, and develops large, complicated systems in which intelligent systems are part of the manufacturing plant control systems.

Most often, an SCADA system will monitor and make slight changes to function optimally. SCADA systems are considered closed-loop control systems and operate with comparatively little human interference. One of the key advantages of SCADA is its ability to supervise a whole system in a real-time environment. This is simplified by data acquisitions, including meter reading and checking statuses of sensors, that are communicated at regular, small-time intervals. An SCADA system as an industrial automation system acquires data from instruments and sensors located at remote sites and transmits data to master station central site for either controlling or monitoring purpose. The collected data from sensors and instruments usually is viewed on one or more SCADA host computers at the central site. Based on the data received from the remote substations, automated or operator-driven supervisory commands can be pushed to remote substation control devices, usually called outstation or field devices.

Large-scale and customer-premise grid-connected solar PV power or wind farm must be equipped with fully functional automatic SCADA system. Communication media are the key to data transmission to ensure the efficiency of the specific

SCADA system, so intensive research and testing of the communication technology are necessary. The SCADA technology of a solar PV power plant is still in the development stage, and the communication solution also is self-contained and immature. Because of the single method, lack of network management, and low level of integration, current communication solutions of SCADA systems are difficult to adjust to accommodate increasing business needs, and so research is focusing on a new solution [15–20].

18.2 SMART GRID CONCEPT

The smart grid framework is composed of and concerned with distributed intelligence, including data decentralization, renewable distributed generation and energy storage, and distribution system automation. Also of concern are customer partnership and interaction, microgrids, and high-demand devices. The smart grid is, by definition, about real-time data monitoring and active microgrid management via rapid two-way digital communication through the implementation of technological solutions to the power delivery infrastructure. Integration exists between microgrids and within the electric utility, renewable power generating devices, consumer loads devices, and third-party entities, either as consumers, vendors, or regulatory organizations. Smart grid comprises an intelligent monitoring system that observes the flow of electrical energy throughout the power network and incorporates the use of cables or transmission lines to manage power fluctuations, losses, and cogeneration integration from solar, fuel cell (FC) and the wind.

Generally, most effective smart grids can monitor/control residential home devices that are noncritical during peak power consumption times to reduce power demand, and return their function during nonpeak hours. Proposals for optimization include smart microgrids, smart power grid, and intelligent grid. In addition to normalizing electric demand, the ability to manage power consumption peaks can support in avoiding brown-outs and black-outs when power demand exceeds supply, and allow for maintaining critical loads and devices under such conditions. Fig. 2 displays a high-level communication flow between different components in a smart grid.

The smart grid initiative has made significant progress toward the modernization and growth of the electric utility infrastructure and aims to integrate it into today's advanced communication era, both in function and in architecture. That evolution comes with a number of organizational, socioeconomic, technical, and cybersecurity challenges. The expansion and depth of those challenges are significant, and a number of regulatory organizations have taken up the initiative to bring their own standards and requirements into alignment with these new challenges. The initiative also has offered many opportunities to explore new areas to take advantage of data communication among distributed and remote electric networks and their devices.

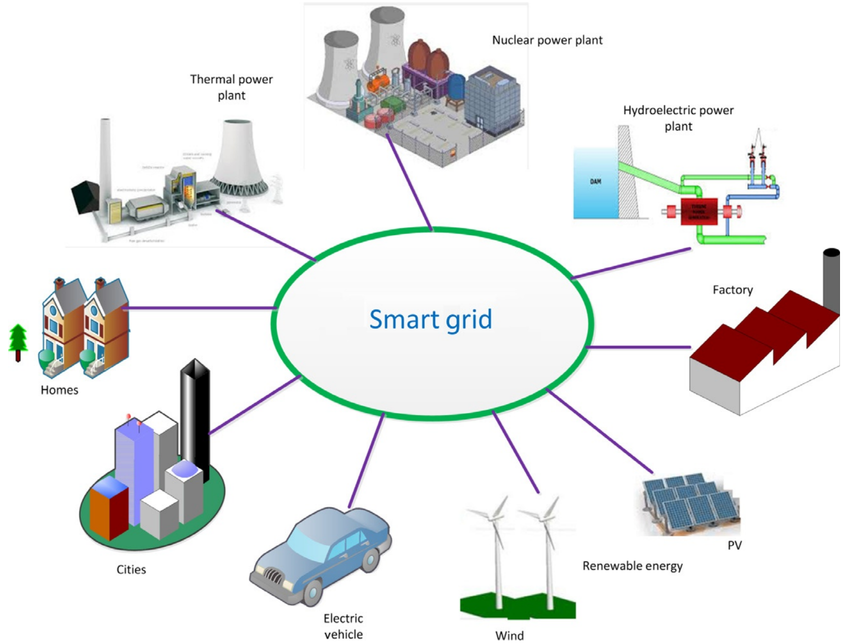

FIG. 2

Smart grid architecture.

18.3 SMART GRID/SCADA INTEGRATION

Integrating SCADA into the smart grid can be accomplished by electrical, communications and data networks, and allows for distributed and central aggregation of information and control over the entire electrical utility network as depicted in Fig. 3. SCADA empowers electricity consumers by interconnecting EMS to authorize customers to manage their own demand of energy and control costs. It allows the grid to be self-healing by responding automatically to power quality issues, power outages, and power system faults. SCADA monitors and optimizes the grid assets, while minimizing operations and maintenance costs. The smart grid, intelligence and control need to exist along the entire power supply chain. This includes electricity generation and transmission from beginning to delivery end-points at the customer's side, and includes both fixed and mobile devices in the smart grid architecture.

Digital communications in a smart grid take place over a diversity of technologies, protocols, and devices that comprise wireless and wired networks, and radio data communications, fiber optics networks, power line carriers, distribution line carriers, and satellite. SCADA software supports the dynamic grid management that encompasses monitoring the line segments and other control points in the electric network. To be fully efficient, every segment of the power line and piece of

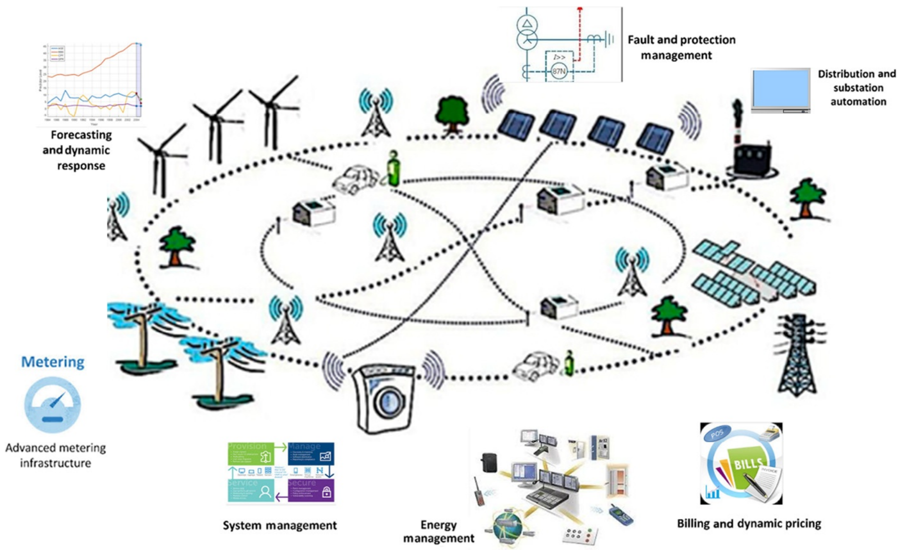

FIG. 3

SCADA/smart grid integration.

equipment in the distribution system should be monitored, in addition to allowing customers to observe and control their own loads and their energy consumption. Then a considerable amount of data has to be analyzed, organized, and utilized for both online and offline decision-making software that can be installed on power applications servers.

Decentralized SCADA software is important because of the significance of SCADA devices, data acquisition, and computation ability, which prevent a centralized data acquisition solution. The IEDs will develop the organization, collection, and data analysis necessary for decision making and switching management, data routing, and other required control actions that might be necessary based on the status of operation. This functionality subsists either as part of the devices' firmware or via RTU configuration functions and settings within each device.

18.4 SCADA APPLICATIONS IN POWER SYSTEM

A SCADA system is widely used in a power system to collect, analyze, and observe the power system data effectively. As the power system deals with power generation, transmission, distribution, and renewable energy sectors, monitoring and control are the main aspects in all these areas. Electric utilities detect current flow and line voltage, to monitor the status of CB, and to take sections of the power grid online or offline. Thus, the SCADA oversight of the power system improves the overall efficiency of the system, by saving costs and time. This can be achieved by optimizing the operation, minimizing loss, and supervising and controlling the generation and transmission systems. The SCADA's function in the power system network provides greater system reliability and stability for integrated grid operation. The power system automation system offers contingency-based fast load shedding, power control and SCADA functionality for the electrical system. These applications might be supplied by different vendors and applications such as:

- Generation/transmission/distribution monitoring and control system
- Generation/transmission/distribution control system
- Generation/transmission/distribution integrated control system
- Generation/transmission/distribution protection and control system
- Power management system
- Switching management system
- Load management system

18.4.1 SCADA FOR POWER GENERATING STATIONS

Advanced control and communication devices are used to deliver an optimum solution for each and every operation with flexible and advanced control structures. This can be done by using of PLC controllers, RTU data acquisition devices and advanced communication links along with SCADA software and hardware in power generating plants and stations. Fig. 4 shows the structure diagram of SCADA in power generation as it supervises several tasks of operation, including protection functions, controlling and monitoring scheduled and unscheduled maintenance procedures. The control functions of SCADA system in power generation include:

- Continuous monitoring of speed and frequency
- Observation of the dynamic status of CB, switches, and protection relays
- Planning of generation operations
- Control of active and reactive powers
- Wind/steam/gas turbine protection
- Monitoring of fuel system and station auxiliary services
- Voltage- and frequency-based load scheduling
- Processing of historical data for parameters related to generation
- Observation of weather stations in case of wind and solar plants.

The SCADA provides an integrated group of control, management, and supervision functions for traditional and renewable power generation stations. These functions include:

- Generator control, including MPPT for solar PV station and yaw control in wind turbines
- CB on/off control
- Integration with protection relays including adaptive protection for microgrids
- Synchronization function between generators
- Transformer and tap-changer control according to the network conditions.

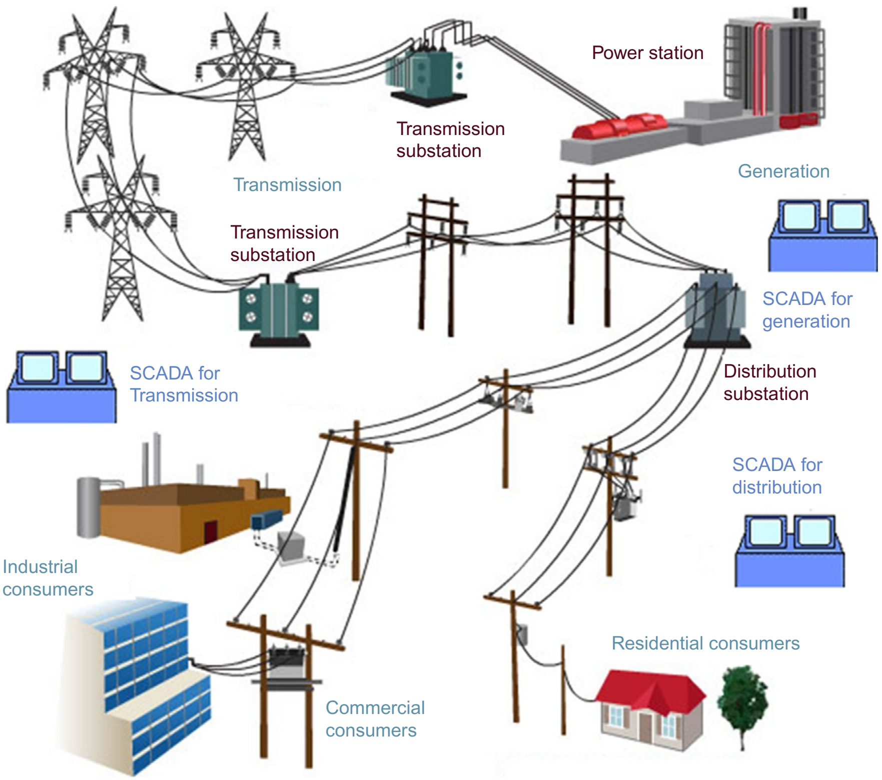

FIG. 4

SCADA for electrical power industry.

18.4.2 SCADA FOR POWER DISTRIBUTION SYSTEMS

EMS deal with electric energy from transmission/distribution substations to the different load types with the use of high/medium voltage cables and transmission lines. Most of the electrical power distribution utilities depend on manual labor to carry out distribution network tasks, such as connection or interruption power to loads, fault removing, service restoration, and taking the voltage and current readings by observation every hour. SCSADA implementation in the power network not only decreases the manual work operation but also eases smooth automatic operations with minimized load disturbance. Fig. 5 shows the schematic diagram of SCADA in a power distribution system where it acquires whole data from various substation components and from pole-mounted distribution transformers at remote locations and processes the corresponding data and status information.

Data acquisition devices such as RTU or PLC in electrical substations continuously monitor the substation CB and transformers and transfer this data to a centralized SCADA system main computer. When a power outage occurs, the SCADA

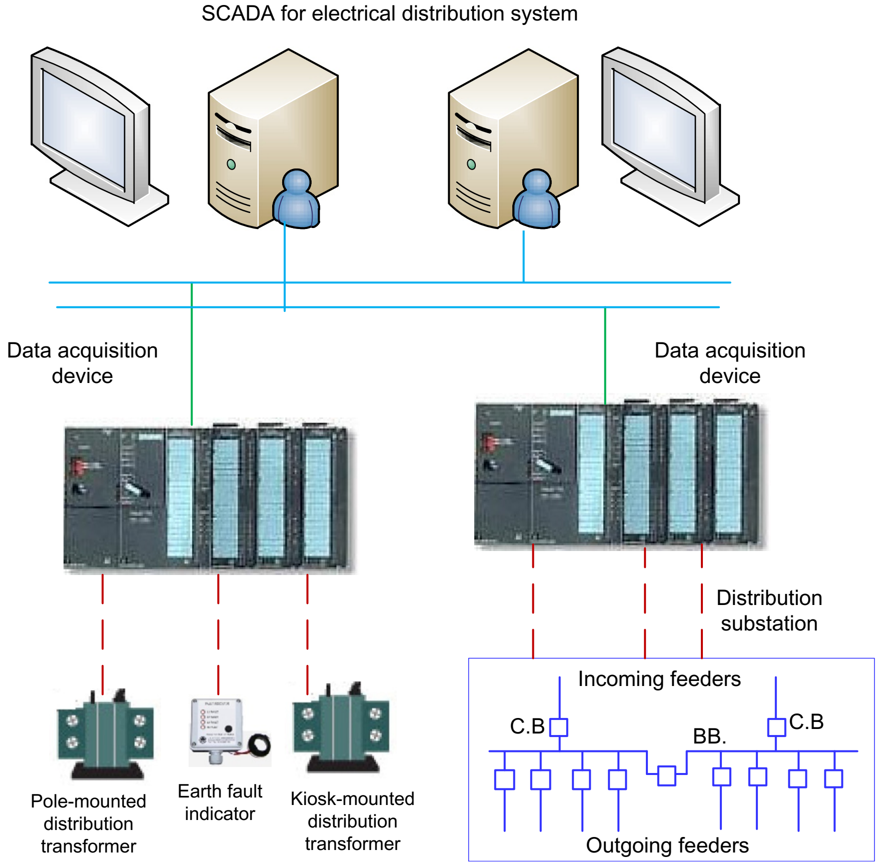

FIG. 5

SCADA for a power distribution system.

system detects the fault type and location, without waiting for customers' calls. SCADA gives an alarm when a control point exceeds or violates the limits. The events and alarms are passed to the operators to identify and analyze, depending on the network operation condition. The SCADA in substations automatically controls the CB, transformers, bus couplers, and earthing switches for exceeding parameter limits; therefore, continuous inspection of network status and parameters are performed regularly without a line worker. Some of the SCADA functions in power distribution system are given as follows:

- Improving power quality by improving power factor and harmonics contents
- Limiting peak load demand
- Real-time monitoring and controlling of power network
- Trending and alarming to enable fixing outage problems

- Historical data and archiving
- Quick response to customer service calls
- Motor control and integrating with SCADA
- Power control algorithms
- Load shedding and load restoration.

18.5 SCADA IN SOLAR PV PLANTS

PV power generation system can be divided into standalone PV systems and grid-connected PV systems. Grid-connected PV power plants consist of a PV array, converter, EMS, and other several parts. A typical distributed network of PV power plants is shown in Fig. 6. An SCADA system can be employed to be a subsystem of EMS in PV power plants. Its core part is an RTU. An SCADA system could manage the PV system using data streams in the range of several thousand measures per second. SCADA software configured to meet solar PV application requirements provides flexibility in controlling and monitoring the different PV plant components, including inverters, trackers, CB substations, and meters.

In the case of a small-scale solar PV system, it is important to assess how much energy the system can produce according to a specific location, orientation, and plant power conversion efficiency. An efficient monitoring system is important to account for the amount of energy produced by a PV system in real time, and to guarantee the forecast conversion efficiency will be accurate throughout the PV panel's service life. A digital meter also is used to measure voltage, current, frequency, active/reactive power, as well as the energy produced. Data loggers supply data into the SCADA database, which can store it for use later. Data loggers record solar radiation data, which defines the number of sunny days in a specific location to be used for prediction and statistics; solar PV system voltage, current, and battery charging to estimate total power production and system efficiency; and solar thermal collection, which provides relevant information for estimating capital costs. The digital meters have serial port communication interfaces such as RS485/RS232 or Ethernet that allow PC to access the data. Most of the electricity supply providers in the world have developed guidelines and standard criteria for interconnecting renewable energy resources into their electric distribution networks. During minimum loading conditions, solar PV installations efficiently reduce the customer load and might inject energy back to the utility grid using a net energy metering package. In IEEE P1547.6, the IEEE recommended a group of standard guidelines to guide PV system users in design and installation of PV systems that can be connected to the utility grids.

Industrial SCADA software should meet its PV application requirements. This SCADA software should provide flexibility in controlling and monitoring the various PV plant components and measurements, including maximum power point trackers, inverters, substations, CB, and meters. For monitoring purposes, the system

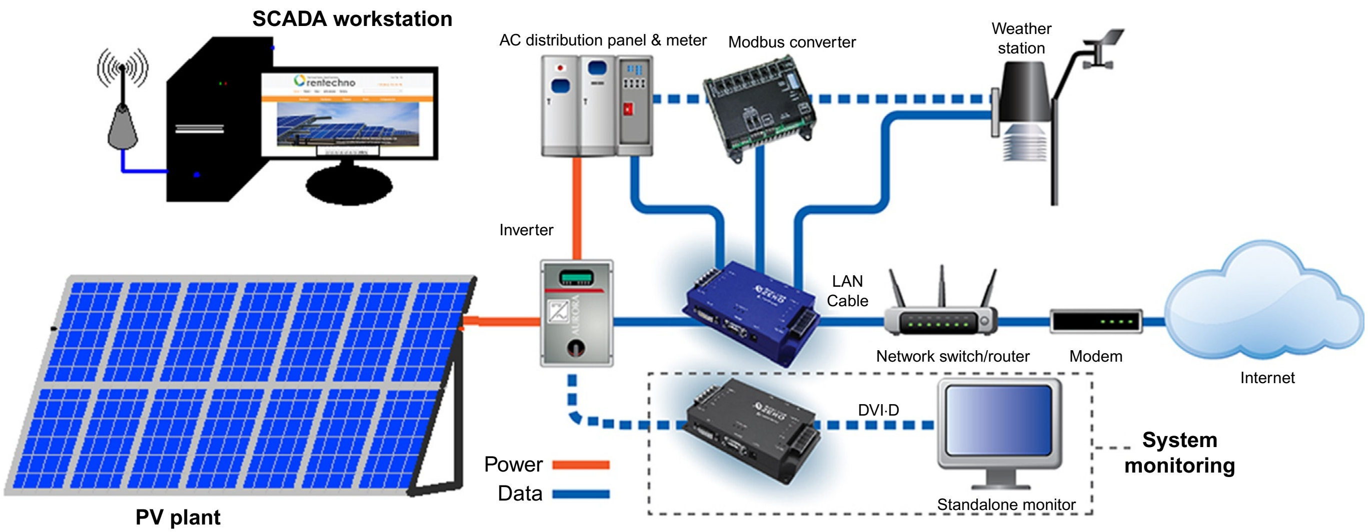

FIG. 6

SCADA in solar PV plants.

records any event and generates alarms so that the engineering staff can order switching action or change the process of plant operation.

An SCADA system monitors PV farm performance by comparing it with the PV plant design datasheet, which includes PV modules' voltage, current at maximum power, open circuit voltage, short circuit current, DC-AC inverter, and charge regulators specifications provided by the manufacturer. PV manufacturers also give electric parameters such as the number of strings and string lengths. The PV model is continuously supported by local weather data and calculates real-time energy production with the full capacity rating. A comparison is made automatically between the calculated and the real production figures supplied by the station data logger. This comparison gives an accurate designation of the station's operational performance and checks the operation status frequently at a predefined time interval. Recent monitoring and performance evaluation of solar PV stations have become highly important because of the high maintenance and operation cost and also because of a reduction of energy produced from aging and degradation during the life cycle of PV plant components. The use of an SCADA system can be essential to ensure high efficiency, less downtime, and fault diagnosis of a solar PV power station during its entire lifecycle.

From a design point of view, it is important to understand how data acquisition in the PV system works, starting from the PV module output. In large solar PV installations, multiple solar PV modules are combined together in parallel to multiply the string output currents to higher levels using DC combiner. The string combiner boxes have consolidated transducer units that measure the analog values of DC voltage and current and then calculate the power. The data acquisition device (e.g., RTU) makes the collected data available through a serial communication port or wireless communication for interfacing the SCADA system via Modbus. In some cases, the RTUs installed at the site substation can be connected to multiple string combiner boxes on the multi-drop serial communication port, RS485. While on the AC side, DC/AC inverter offers RS485 ports to allow a proper connection for the SCADA interface. The communication software drivers collect time-stamped data from control boxes and RTUs for computer processing, violation alarming, report generation, archiving storage, and displaying in real time. All the DC and AC side measurements, status, substation alarms and failures are acquired continuously. The SCADA system also interacts with digital protective relays, digital power meters, environmental monitoring station, low tension (LT), and high tension, control panels, inverters, DC switches, charge regulators, transformers, and, in general, any devices installed in the PV plant. In order to make PV applications effective, scalable, and potentially sustainable, other design aspects of the SCADA platform can be taken into account. These aspects include a dynamic configuration, redundancy for data protection, standalone and client-server configurations, historical and real-time values, graphical trends, oscillography analysis, and advanced management of system alarms. Regarding standards compliance, communication protocols such as IEC 61850 and DNP3 are key elements to if SCADA is required to communicate with several PV plant devices. The application software such as the graphical user interfaces (GUI), report generator, switching management, and scheduler, will enable easy access of all data. Another option is Web-access functionality, which provides all kinds of capabilities and can access a remote site.

18.6 IMPROVING WIND-FARM OPERATION USING SCADA

The SCADA application for wind farm operation can improve the actual power conversion efficiency. Modern wind farms contain a variety of measurement devices, SCADA components, and communication systems. For reliable, safe, and automated control, individual wind turbines use microprocessors with closed-loop control algorithms to regulate internal control, which include pitch, yaw, generator, and supervisory controllers. The safety system is hardwired independently of the main controller for fail safe, i.e., for emergency shutdown. The historical data about the wind farm response because of wind speed variation and wind gusts can be gathered in the wind energy assessment study. This study includes wind resource measurement, data analysis, site assessment, and wind performance evaluation, due diligence and forecasting [21]. The SCADA dataset is composed of four stages: wind speed, energy conversion system, effect of temperature, and vibration issues [21,22]. The SCADA data usually are analyzed for fault identification to aid the operation experts in a fault isolation and service restoration. The monitoring of the wind farm enables modeling the power curve of a specific wind turbine. The graphical analysis is a method for extracting and processing information on a daily basis from the meteorological mast database and from the SCADA systems database. The graphical method also is an appropriate and meaningful way to highlight the most regular power production and nacelle wind speed variations along the wind farm. It is important to monitor the farm performance in order to detect possible malfunctioning of individual turbines and quantify the influence of variations on the electrical output power production.

Reducing operation and maintenance costs can be achieved by improving wind turbine performance. Lessening these costs can reduce the payback period greatly, help level the cost of electricity, provide a motive for investors, and support spreading this type of clean energy source [22]. Maintenance costs can be reduced by using SCADA technology to control and monitor onshore and offshore wind turbines. Wind turbines usually work in stiff, remote environments, and, for this reason, need maintenance on a regular schedule. The outage maintenance or unscheduled maintenance because sudden failures can be costly because of lost production time and in addition to maintenance expenses. As wind turbines age, parts can fail and energy production degrades, thereby increasing maintenance costs as a percentage of power production. The field data is analyzed to enable preventive maintenance rather than rely on time-interval-based maintenance. The monitoring of wind turbines discovers failures before they reach a serious state, increases equipment lifetime, keeps the electrical and mechanical equipment working at rated capacity, enables better planning and logistics, and can reduce the need for regular maintenance.

Condition monitoring systems for wind farms have focused on detecting failures in the main generator, bearings, and gearbox, which are the highest cost components of a wind turbine [21,22]. These are standalone systems that require the installation of sensors and hardware. An SCADA-based condition monitoring system uses collected data to prevent catastrophic failures by an early alarm of primary faults. Different approaches are available to use SCADA data to predict the health of operational wind turbines [23–29]. Wind turbine reliability remains an important focus for wind turbine owners, operators, and manufacturers [30], and condition monitoring can improve reliability and reduce downtime [31]. The use of SCADA data for wind turbine condition monitoring has a number of advantages, in particular, the data already are collected, so no additional hardware is required.

Yaw controller rotates the wind turbine into or out of the essential to mitigate fatigueloads, maintains optimum electrical energy production, unwinds power and control cables between nacelle and base or generator controller which adjusts torque to maximize electrical power output and maintain rotor speed below the rated one. It is also actively dampen drive train torsional vibrations by applying small ripple torque closer to drive train natural frequency and phase angle.

Wind farm supervisory controller is necessary to operate wind turbine autonomously from one operational condition to another at the start-up, power production, and shut-down conditions. The primary functions of the proposed control and management system are: (1) Supervision and control the interconnection of the wind turbine power plant to the utility grid, (2) Control the performance of the generator and power converters output, (3) Optimizing the energy conversion efficiency of the wind turbine, (4) Providing system performance measurements for operator evaluation, (5) Achieving safe shutdown under normal and fault conditions, (6) Operation and monitoring of auxiliary equipments such as cooling of gearbox, fans and pumps, heaters for cold weather applications and lubrication pumps.

The SCADA server might be located on site or in a control room, depending on communication access to the wind turbines, which means one SCADA might monitor multiple wind turbines regardless of their location. An IP connection could link single turbines or small clusters of turbines so they are continuously monitored and controlled by an SCADA server in the control room, Fig. 7. The OLE for process control (OPC) server is a software program that converts the PLC communication protocol into the OPC protocol. The client software is the application program that needs to connect to the hardware, such as a power plant human machine interface (HMI). To get data, the OPC client uses the OPC server and send control commands to the hardware.

SCADA software enables monitoring wind energy systems, and allows controlling individual turbines, as well as the entire wind farm. The collected data help in blade design, aeroacoustic measurements, and ways to obtain optimum performance. SCADA functions are divided into three main functions that cover all areas of an integrated SCADA solution:

- Real-time monitoring and control of wind farms
- Handling events and alarms for the wind farm subsystems
- SCADA servers that collect and process the system data.

The wind farm is heavily instrumented and provides a lot of data about aspects such as wind speed, turbine output power, blade angle, stall level, and yaw. The wind turbines can be accessed via a suitable communication method such as wireless

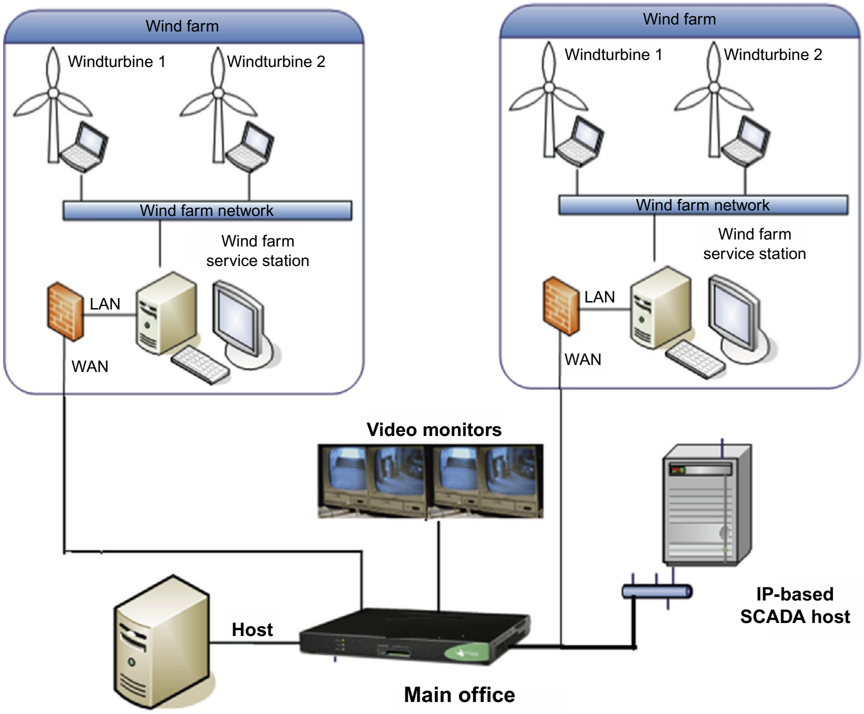

FIG. 7

Schematic diagram of SCADA system in wind farm.

communication, telephone modem, or even transport control protocol/Internet protocol (TCP/IP). The SCADA software should provide a complete control and monitoring of each wind turbine and the entire wind farm. A graphical overview of the wind farm shows the status of each wind turbine and related measurements such as voltage, current, wind speed, and production data. To determine the corresponding alarms, the software should be supported by the turbine specifications, including all relevant parameters of the used wind turbine, including the rated wind speed, temperatures, pitch angle, generator and rotor speed, rated electrical parameters, yaw control system.

18.7 FUEL CELLS CONTROL AND MONITORING

Fuel cell (FC) is a DC power generator that converts the fuel chemical energy (hydrogen, natural gas, methane, methanol) and an oxidant (air or oxygen) directly into electrical energy. While several FC technologies are available, the most popular and practical technology for a small to medium-sized standby power supply is the proton exchange membrane (PEM) FC that produces electricity through an electrochemical reaction using hydrogen and oxygen. This electrochemical reaction happens without any combustion process. An FC operates electrochemically through the use of an electrolyte, like a generator that operates as long as the fuel is supplied.

FCs are designed to provide stable electrical power while operating over a wide range of power and environmental conditions. Advantages of FCs include high efficiency, simple, quiet and clean, low maintenance and noise with few moving parts, no harmful emissions, and economical cost for stationary standby power generation [32–34]. FC systems are load-following because fuel consumption depends on the load. FC power systems are designed for a wide range of customers, including hospitals, hotels, universities, utilities, and water treatment facilities. The applications of next generation high temperature FC products, such as diesel-fueled marine ship FCs, combined-cycle FC power plants, and next generation solid oxide FCs (SOFC). The PEM FC's higher efficiency, environmental friendliness, and modularity have made this system one of the most attractive candidates for both transportation application and stationary standby power generation.

The criteria for selecting an FC standby system for a specific application include the output power requirements, frequency and duration of power failures, response time to the load, environmental restrictions, and service requirements. FCs can be used as the sole backup/emergency power solution in many critical applications, and they also can provide an added degree of protection for a site using resilience solutions. FCs can offer rack-mounting options within an equipment shelter as well as reinforced, environmentally friendly, outdoor cabinets for flexibility to meet electrical network demand. The ability to refuel FCs allows the system to run continuously as long as required during extended outages. In fact, FCs can be the selected backup power source at sites with comparatively low power loads and power failures that can last for hours or even days.

18.7.1 INTEGRATING AN FC INTO AN ELECTRICAL NETWORK

Another advantage of an FC that makes it attractive for use in standby power environments is that an FC produces DC power. It is similar to a standby rectifier power source, Fig. 8, because the power provided from the FC can directly feed the site's DC power bus. In a power outage situation, the FC automatically turns on, providing DC power formerly provided by the utility through rectifiers. This means FCs can work for long reserve times as a standby power supply in customer critical applications. FC systems are proposed to work in parallel with the traditional DC power system components. FCs can be integrated easily into an existing power network or can be designed into a new standalone network location. They can also be part of a clean power hybrid system also composed of solar and/or wind power. A variety of FCs are capable of serving loads in a variety of critical geographical locations because of hot and cold weather design features.

The SCADA supervisory controller for FC systems is necessary to operate the fuel cell and monitor all the auxiliary systems such as electrolyzer and cooling and auxiliary systems. The typical applications of FC SCADA system are:

- Cell voltage monitoring of fuel cell stacks
- Cell voltage monitoring of battery packs
- Cell voltage monitoring of electrolyzers or other electrochemical multi-cells

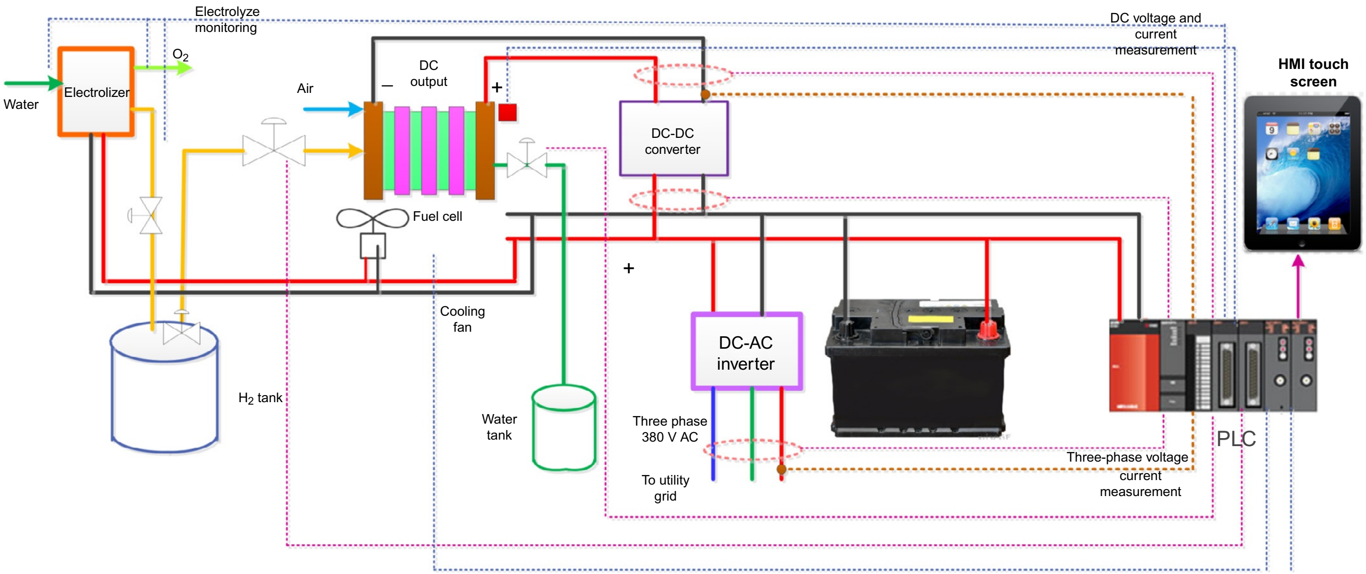

FIG. 8

Fuel cells to provide backup to their communications equipment.

- Temperature monitoring of up to four locations
- Digital input monitoring for coolant flow loss or other alarm conditions
- Protection functions using solid state relays and control output for auxiliary relay
- Operating limits and monitoring of temperature, voltage and current measurements
- Automatic shutdown of relay and contact outputs for cell over-voltage, cell under-voltage, and cell over-temperature conditions
- Monitoring indicators of power, alarm, low-supply voltage, and station alarms

18.7.2 BENEFITS OF THE FC SCADA SYSTEM

SCADA systems can provide solutions for the monitoring and control of their FC systems. The solution includes HMI/SCADA application; real-time automation software; and the alarm and events management system. An FC power system requires a user-friendly, robust HMI, secure to allow monitoring and remote-site control of the FC power stations as standalone/grid-connected systems. The SCADA system also can provide the FC power system with alarm management and real-time functionality. The dispatchers at the control room can acknowledge or take action when they alerted by an event or alarm. The Internet-enabled HMI control promotes ease of use and remote control/monitoring of that kind of power system. Another benefit is the integration into existing microgrid systems. SCADA delivers the facilitated Internet-based remote access HMI. The SCADA delivers also an event/alarm management that is required for remote monitoring/control of a standby FC power station working in either standalone or hybrid modes.

Because of the specific nature of FC systems, measurement, supervision, and control devices are substantial. It is interesting to find a system enable the real-time monitoring and control the performance of a PEM FC system. The control process occurs according to the instructions recommended by the FC stack manufacturers. The automation of FC station is based on an SCADA system that acquires data and monitors the input/output measurements and control signals [32,33]. The SCADA system stores data in an organized process database. The SCADA platform consist of three main elements: an SCADA server, the FC system controller, and memory storage device. The SCADA server provides access to the system's electrical parameters and configures interface through serial communication. The SCADA user can access the data for analyzing, reporting, or making engineering tasks for system expansion. In the beginning, the main screen of the SCADA system enables users to select the role in which they wish to work (operator, engineer, or administrator). The software tool has a detailed description of the FC plant and rated input/output values, rated operating parameters, proper control interface, and station operation. The SCADA software traces the dynamic changes in the site and sends data to the master station control room, which supervises the whole system.

The FC current and voltage transducers are being connected to analog input terminals of RTU, and thus monitoring voltage and current, as shown in Fig. 9. If an FC is run above its rated current for long periods of time, it can contribute to equipment

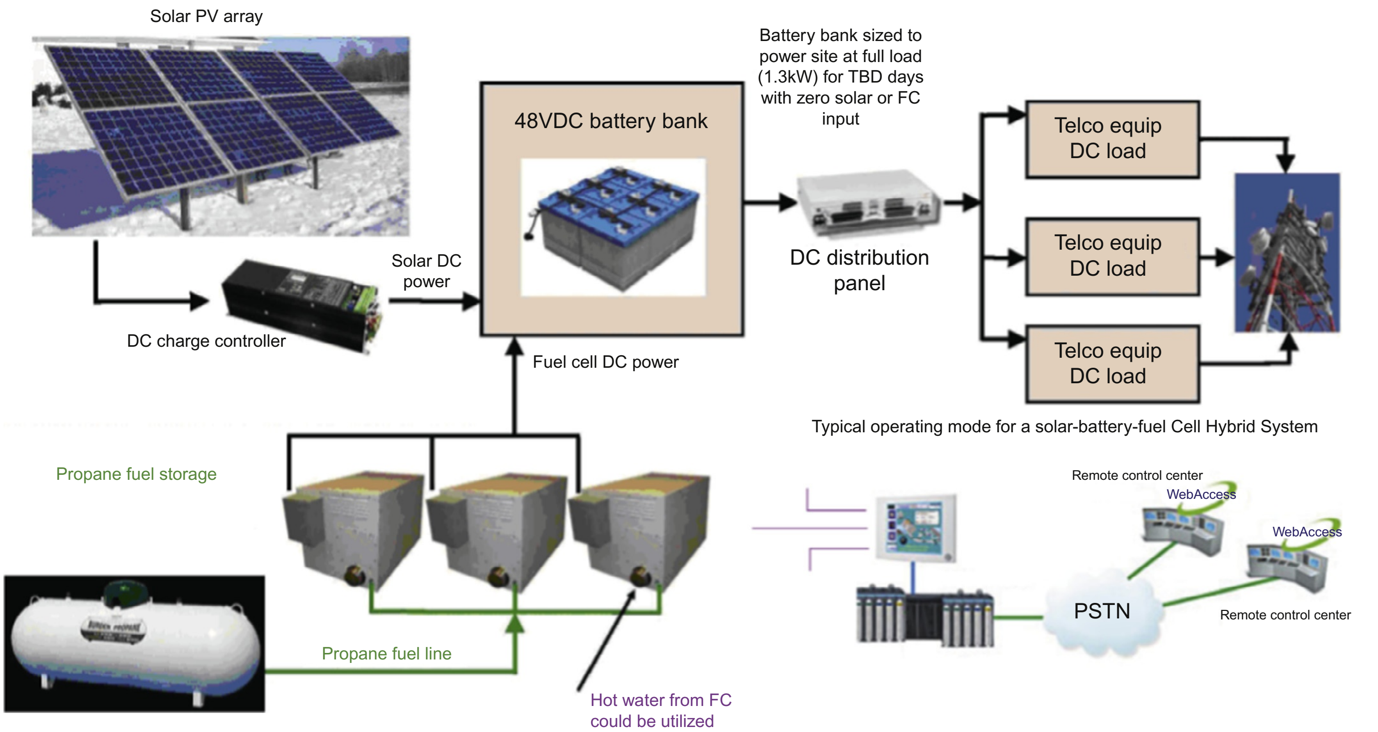

FIG. 9

Schematic diagram of SCADA for standalone fuel cell hybrid system.

degradation, so monitoring the fuel voltage guarantees that increases in FC stack current doesn't drive the cells into reversal. Cell reversal results in heat, and can result in a cell-to-cell short circuit and an electrical arcing. A blocking diode is placed in series to prevent reversal currents, and a protective relay is added to protect the FC system from external faults. The SCADA is responsible for receiving information from all the subsystems and enable them to work simultaneously. An external power source is required to supply all the devices in the balance of plant, including the FC. This external power source is necessary because the balance of plant devices should be powered even before the FC system begins working, and because of the extra time required for the FC system to reach steady-state operation and deliver rated electrical power [32].

18.7.3 CONTROL AND MONITORING SYSTEMS

Several attempts have been made to design FC systems to significantly improve their performance, reliability, efficiency and durability. In some types of PEM FCs, the main reason of a short lifecycle and degradation are thermal stress and water, corrosion, reduction of fuel and oxidant, and chemical reactions of the FC components. Thermal management is essential at cold start-ups, while bad water management can result in dehydration or flooding [33]. For these reasons, the operating procedure of FC system should be designed to ensure high efficiency, good performance, durability and safety. These procedures are established by the supervisory control system. The SCADA must observe the measured values of different variables and keep them within the admissible range to avoid sudden FC damage and irreversible performance degradation. If the FC system gets in a critical alarm condition, it is required to carry out a forced shutdown. The robustness and resilience nature of the network is essential, regardless of the type of communications network that is used for SCADA systems. Recent natural disasters have demonstrated the importance of communication systems to microgrid and utility grids. To have a resilient power network, the communications equipment also must provide resilience operation and reliability. FCs increase power reliability of communication networks by providing backup/standby power to many sites throughout the distribution networks.

18.8 USING SCADA IN HYBRID POWER SYSTEMS

Energy demand—either in standalone or grid-connected modes of power systems—is increasing steadily. The challenge is to meet that increasing demand for power, while acknowledging the public interest in global environmental concerns, such as the effect of greenhouse gases and global warming, and the reduction in fossil fuel resources. These problems can be solved by recent research and development of alternative RES. Introducing RES, such as solar PV, FC, and wind energy has an excellent potential of contribution to power generation. These sources are clean and abundantly available in nature, and offer many advantages over conventional sources of power generation. Combining two or more RES forms a hybrid power

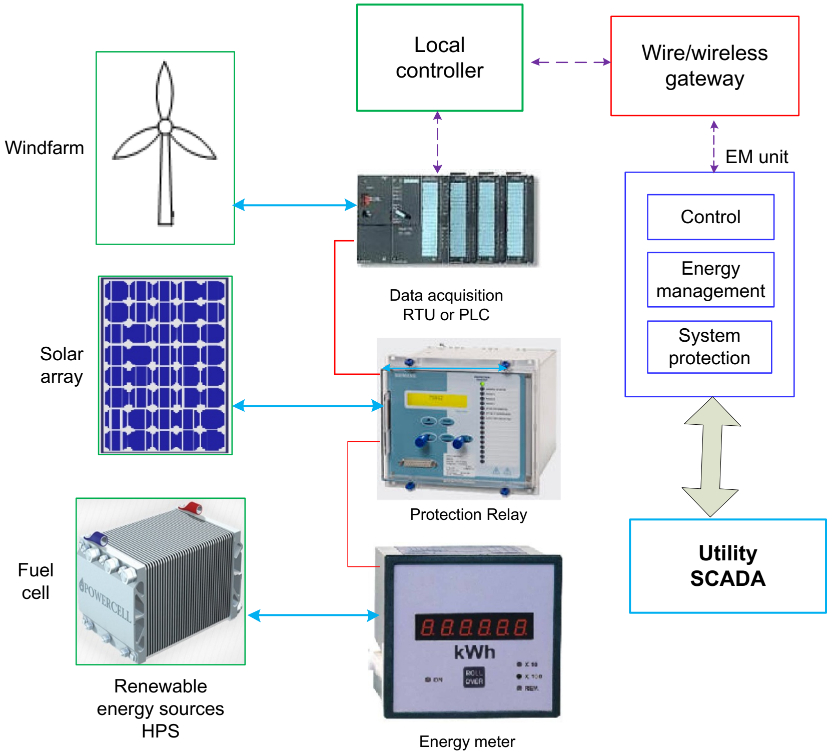

FIG. 10

Schematic diagram of renewable energy-based hybrid power system.

system (HPS). A schematic diagram of a hybrid renewable power system is shown in Fig. 10. The reliability of an HPS mainly relies on the dynamic behavior of the RES, so it is important to analyze these dynamic characteristics in real time for long time periods. A major challenge lies in the development of a real-time control scheme for the HPS. To test the HPS controllers, a controller must be able to interface with a hardware simulator and process the inputs and outputs in real time. Today, the improvements in communications systems have prompted the implementation of the HPS using PLCs and RTU control schemes by a centralized supervisory control platform, which is commonly known as an SCADA system. All the modules should be modeled in the PLC environment. PLC and SCADA system communicate with each other over a dedicated protocol that can be transmitted over a serial port or Ethernet.

The control structure of HPS is shown in Fig. 10. The monitoring of PV cells and FCs is done in PLC and is interfaced to SCADA/EMS so that the operator can observe the parameters easily and control the parameters according to the changes in system requirements. The data of HPS is collected through PLC and connected to the control room through a communication protocol. The detailed connection of RES, such as

HPS, is shown in Fig. 10. The PLC is interfaced to the energy management control unit to get control actions according to the respective microgrid loads and environmental conditions. The entire system is connected to SCADA for supervision and control. The control room contains various I/O consoles, such as engineering and operator consoles. The engineering console is responsible for adding new points or new IED devices to the system.

18.9 SCADA SYSTEM ELEMENTS

The real-time data collected by the SCADA system is then passed to the planning engineers for consideration in development studies of the distribution system. Because of growth of the electricity distribution industry, utilities make annual investments to improve efficiency of the electric distribution system to satisfy the growing load requirements. Real-time data enable engineers to effectively plan the annual capital expenses needed to face the needs of the growing electric network. Electrical power quality issues include reduction of harmonic content to an acceptable total harmonic distortion (%THD) that is defined by international standards. This monitored information is used as a key performance guide of the electric power network.

In general, of the main elements of an SCADA system are:

1. Host equipment or master station hardware
2. Communication infrastructure (communication networks and equipments)
3. Field devices or outstation hardware to support control operations and telemetry requirements of a DMS platform

The components of the SCADA automation system in the master station can be divided into four major areas:

1. SCADA and database servers
2. DMS/EMS applications and server(s)
3. Trouble management/switching management applications servers
4. Front end processors (FEP) or communication servers

The above components of SCADA system usually are intended to perform four functions:

1. Data acquisition
2. Networked data communications
3. Data display and presentation
4. Control functions

18.9.1 HOST COMPUTER SYSTEM

The host computer network usually is known as a master station or simply control room, or SCADA control center. The central host computer could be a standalone single computer or a network of computer servers. This computer network provides process control remotely or locally for all SCADA system devices, supporting requested supervisory control and a remote method of acquiring measurement data, alarms and events for monitoring power supply processes. The SCADA host platforms also provide functions for dynamic graphical displays, alarming, logging, variables trending, and historical data storage.

The essential elements of SCADA platform are:

1. Host servers (redundant server network with backup/failover capability)
2. Communication FEP
3. Full functionality graphics user interfaces
4. Relational database servers for archiving power system historical events. The data/Web servers are enabled for access to system points in real time (measurements values, CB status and events)

The major elements and system components of the typical master station or control center are illustrated in Fig. 11.

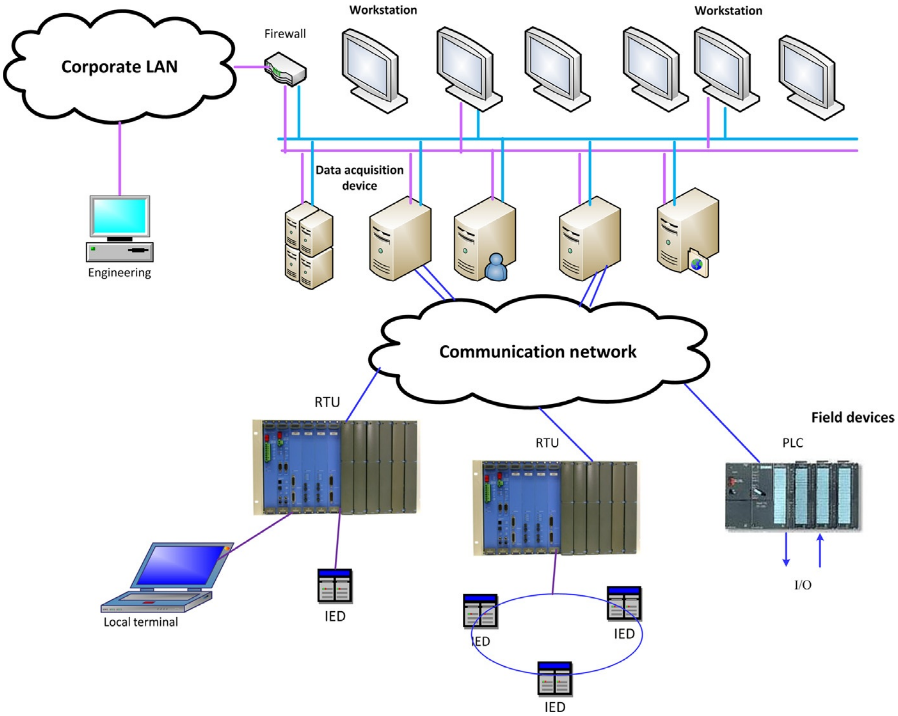

FIG. 11

Master station system architecture.

SCADA servers

As SCADA systems have proven their vital value in operation during stormy weather conditions, fault isolation, service restoration, and daily operations, the reliability of SCADA has become a requirement for highly reliable, available, and efficient-performance systems. Redundant server network hardware operating in a "live" backup/failover mode is required to withstand the high availability design criteria. High-performance servers with abundant physical memory are also required, in addition to, redundant array of independent disks hard disk storage systems.

Communication servers or FEP

The current state of the host to field communications devices still depends heavily on serial communications interfaces. This requirement is satisfied by using the FEP, which can be organized in several forms based on data bus architecture and operating systems. The location of the FEP in relation to the SCADA server can vary based on system requirements. Some configurations locate the FEP on the LAN with the SCADA server, but in other cases, existing communications hubs might dictate that the FEP reside at the communication hub. The incorporation of the wide area network (WAN) into the architecture requires a more robust FEP application to sustain reliable communications as compared to LAN configuration. In general, the FEP will include three functional devices:

1. A network/CPU board
2. Serial cards
3. Possibly a time code receiver

The FEP's functionality should include the ability to download configuration and scan tables. The FEP also should support the ability to report limit violations for those analog values that have changed by a user-defined amount. FEP network and SCADA servers should have the ability to deal with worst-case conditions (i.e., all points changing outside of the dead-band limits), which typically happens during severe system disturbance conditions.

18.9.2 FULL GRAPHICS USER INTERFACE

The recent trend in the GUI is a full graphics (FG) user interface. Although character graphics consoles still are used by many utilities, SCADA vendors are aggressively moving their platforms toward an FG UI. FG displays prove the ability to display power system dynamic microgrids and networks, renewable power plants, along with the electric distribution substations in a geographical or semi-geographical perspective. The advantage of using an FG interface becomes evident in particular for electrical energy control centers, as SCADA is developed beyond the substation control room where feeder diagrams become critical to distribution operations.

18.9.3 RELATIONAL DATABASES, DATA SERVERS

A relational database is defined simply as a collection of data points organized as a group of formally described tables where data can be entered or reassembled in many different ways without having to reorganize the database tables. Power system quantities such as CB status, bus coupler status, digital alarms and feeder loading (MW, MWH, MVAR, and three-phase ampere loading), and bus volts support valuable information to the energy systems planning engineer.

The availability of event data loggers is important in fault analysis. Using relational databases, data servers, and Web servers by the operation and engineering functions provide access to power network information and data while preventing the SCADA server from non-operating personnel.

18.9.4 HOST TO OUTSTATION HARDWARE COMMUNICATIONS

Serial communications to outstation devices can be implemented through several media: copper wire (RS485/RS232), fiber, radio, leased line, and even satellite. Leased telephone circuits, fiber, and satellites, however, have a comparatively high cost, and new radio technologies offer an attractive communications solution. One of such technologies is the multiple address radio system (MAS). The MAS usually operates in the range of 900 MHz and is omnidirectional, enabling radio coverage in an area with radius up to 25 miles, depending on terrain. A single MAS master radio can collect data from many remote sites to a concentrator. Communication protocol and bandwidth can limit the number of RTU that can be connected by a master radio. The protocol limit is simply the address range supported by the protocol. Bandwidth limitations can be substituted by the use of effective protocols, or by slowing down the scan rate to include more remote units. Combining spread-spectrum and point-to-point radio with MAS offers a chance to address-specific communication issues. MAS radio currently is preferred to packet radio; MAS radio communications tend to be more suitable for smaller timeout values on communication responses, scan time, and controls.

18.9.5 FIELD DEVICES

Distribution automation (DA) or DMS outstation devices are multifeatured installations with an extended range of control, operations, planning, switching, and system performance issues for the utility personnel. Each device provides specific SCADA functionality, supports system control operations, includes fault detection, collects planning data, and records power quality information. These devices usually are found in the electrical power substation and at specific locations along the transmission line. The multifeatured capability of the DA device increases its ability to be used in the electric power system. The functionality and operations capabilities supplement each other with respect to the control and operation of the electrical microgrid and grid.

18.9.6 MODERN RTU

Modern RTU is modular architecture with advanced capabilities to support data processing functions. The modular RTU design configurations make it available for installations ranging from a small point count site, such as a pole-mounted distribution transformer, to a very large number points in a large power substation. Modern RTU modules include expandable analog input/output, digital input/output points, accumulated input units, and communication cards with power supply. RTU installation requirements are met by assembling the required number of RTU cards or rack-mounted modules to accommodate the analog, control, digital, and communication links for the site to be supervisory controlled. The packaging of the reasonable point count RTU is chosen for the distribution line requirement. The SCADA for substation automation has the option of installing one RTU in one cabinet with connections to the substation IEDs or installing a master RTU and number of slave RTUs at different locations within the substation and connected to the master RTU with fiber-optic communications. The distributed RTU modules are integrated to a data concentrating unit, which, in turn, communicates with the host SCADA computer system.

The modern RTU can accept AC inputs from a variety of measurement (digital meter) and protection devices (digital relays) through a serial port. The RTU can take the measurements as hardwired from CT, potential or VT, station service transformers, and transducers. Direct AC inputs with the processing capability of the modern RTU support fault current detections and harmonic content measurements. The fault location algorithm can be embedded in the RTU firmware, giving the RTU the ability to report the direction, magnitude, and duration of fault current with time tagging of the fault event to 1-millisecond resolution. Monitoring and reporting of harmonic content in the distribution feeder also could be included in the RTU. The digital signal processing capability of the RTU supports the necessary calculations to report THD for each of the three-phase voltage and current measurement at the automated distribution feeder or substation site. The RTU configuration software can include the logic capability to support the development of control algorithms to meet specific operating requirements. Automatic transfer control schemes have been built using automated switches and RTUs with the high processing capability. This high capability provides another benefit to the design engineer when developing the quality of service and addressing critical load concerns. The logic capability in the RTU has been used to create an algorithm to control switched capacitors for operation on the distribution feeder. The capacitors are switched on at zero voltage crossing and switched off at zero current crossing. This algorithm can be specified to switch the capacitors for various system specifications, such as voltage, power factor, reactive load, and time. The remote control capability of the RTU allows the distribution operator to take control of the capacitors to meet inductive load needs. These new logic and input capabilities have allowed the modern RTU to become a dynamic device with increased processing capabilities, uses, and applications.

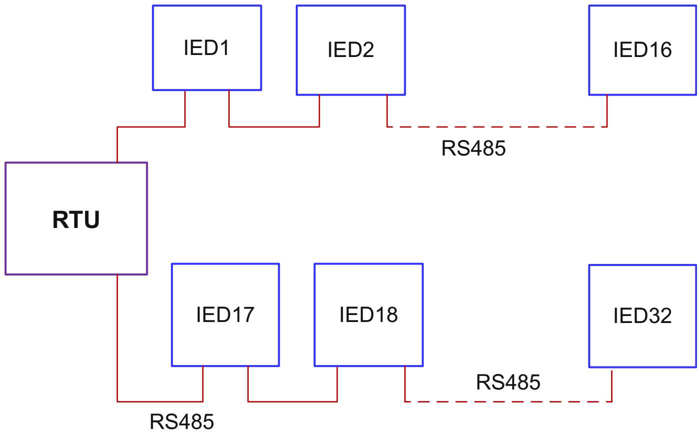

FIG. 12

Connection of IEDs to the RTU using serial port RS485.

18.9.7 PLCS AND IEDs

Programmable logic controllers (PLCs) and IEDs are the main site components of the distribution automation system, which meet specific operating and data gathering requirements (see Fig. 12). The IEDs in substation include digital protection relays and digital meters. While there is some overlap in capability with the modern RTU, the PLCs can be integrated with the RTUs in the substation to assist in its remote operation. The typical PLC can support serial communications to an SCADA server. The RTU has the capability to communicate via an RS485 interface with the PLC. IEDs include digital meters, digital relays, and switchgear on specific substation equipment, such as breakers, switches, regulators, and load tap changer on power transformers. The IEDs have the ability to communicate with an SCADA server through serial or Ethernet ports, the IEDs typically report to the modern RTU via an RS-485 interface or via status output contact points. RS-485 is preferable to RS-232 because it supports long distance, high speed, and several IEDs can be connected in series. Recently, IEDs become attractive in the automation process because of improved communication capabilities.

18.9.8 RECENT TRENDS IN SCADA COMMUNICATIONS

As in many traditional data communication networks many types of communication methods are supported from PLC/RTU to central/distributed SCADA systems via local and wide area networks. A local area network is included within a small geographical area, such as an industrial building or a campus and might include a few buildings in close proximity. A wide area network, however, integrates many LANs spread widely across different cities at least 100 km (67 miles) apart [35]. These types of WANs include the following:

- Analog point-to-point and multipoint modem networks
- Frame relay type point-to-point and multipoint networks
- Wireless radio/satellite communication networks
- Fiber-optic-based communication networks

An SCADA network currently might be built around many of the above possible collection of networks and transmission protocols. Communication solutions for SCADA platform, include the physical wiring, network and communication protocols of the local and wide area networks such as Ethernet and frame relay. TCP/IP suite is a different, but similar open standard used by all).

The RTU/PLC protocols are emerging as practical standards in SCADA systems such as Modbus and distributed network protocol (DNP). Fieldbus, including technologies such as Modbus, CANbus, Profibus, LonWorks, and many other technologies, is mainly used to solve data communication between intelligent sensors, digital meters, controllers, digital protection relays, actuators and other outstation devices. It currently is the most popular used and comparatively functional industrial communications technology.

The point-to-point Modbus protocol has become a practical standard for RTU and PLC communications. During communication on a Modbus network, the protocol specifies how each controller will know the device address, recognize a message addressed to it and determine the required action to be taken and evolve any attached data to it. DNP, a member limited protocol used in some power systems, has various versions, with the latest being version 3.0. The DNP association has rules, which tend to limit the utilization of the protocol, and main SCADA software suppliers have been slow in implementing this protocol.

Industrial Ethernet is technically compatible with IEEE 802.3 standards and is widely used in industrial SCADA and control systems. The industrial Ethernet, however, should meet the requirements of the industrial field in real-time, material selection, reliability, product strength, and environmental applicability. Its main technical advantages are wide range of applications, the high speed of communication, security of control network, and support of a variety of physical media and topologies.

Telecommunications

In the world of communication technology two types of networks exist: circuit switched and packet switched. The circuit switched network establishes direct connection between two or more stations by means of switches, normally done with telephone dial-up modem networks. There is, however, a general shift toward a packet style operation where the data is handled in packets prefixed with some addressing. In a packet-switched network, data is routed through best possible route in a complex meshed public, private, or local area network. Packet switched networks are more cost-effective because a dedicated network is not requested from start to finish.

Wireless networks

Wireless networks come in many flavors and styles. The mechanisms of large-scale remote industries can be controlled more effectively and safely using wireless SCADA, which is the most economical and time-saving technology. SCADA is used in the power industry with the perfect human machine interface. It has solved many issues related to supervision, data acquisition, controlling, and monitoring. It has divergent applications such distribution management, energy management, power plant management, water treatment, and oil and gas distribution system. SCADA also has enabled grid monitoring so the power can be bought and shared on a national basis. The application of SCADA is beneficial to the power systems sector, as well. These wireless networks include

- Satellite networks
- Licensed VHF and UHF point-to-point and multipoint radio
- Spread spectrum license free (900 MHz, 2.4, 5.8, and 24 GHz)
- Point-to-point microwave

Within a narrow range of buildings or a campus, wireless data can be moved from node to node with privately owned spread spectrum radio networks. Broader ranges require some form of public network. The most common method is dial up.

Power line carrier communication

Power line carrier (PLC) communication technology transmits data through the power line. The PLC technology is making use of high-voltage power lines (10 kV or above, and low-voltage power lines 220 or 380 V) for the development and promotion of remote meter reading. The use of PLC is expanding into the distribution lines for load control and even into households to control lighting, alarm systems and air conditioning and heating. The main application, however, is protective relaying for transmission lines. A channel is used in line protection so that both ends of a circuit are cleared at high speed for all types of faults, including end zone faults. A PLC channel also can be used to provide remote tripping functions for power transformer protection, shunt reactor protection, and remote breaker failure relaying.

The main advantage of PLC is eliminating the difficulty of installing additional dedicated communication cables. The disadvantages of PLC are obvious, too. The power line is a very bad channel for communication, mainly because of interference and signal attenuation. Interference comes from power electronic devices, low-voltage load, switch operation, and broadcast signals. In such a noisy environment, it is difficult to ensure data quality. Signal attenuation is brought about by the complicated structure of the power grid, which gives signals multiple transmission paths. The power line communication environment, therefore, is too severe to ensure reliability and stability. The solar PV power station has many power electronic devices, such as inverter, static var compensator, and static var generator. These devices arouse harmonic interference into the AC power line, so PLC should not be used on the AC power line. The DC power line between PV convergence box and inverter, however, has less interference and a single transmission path, and can implement PLC technology.

18.10 CONCLUSIONS

In this chapter, the smart grid initiative was explored, and integration of SCADA systems into the smart grid was described, including an overview of the problem domain as a whole. The evolution of the smart grid initiative to improve the electric utility power infrastructure has brought with it a number of opportunities for improving efficiencies and performance. Along with those benefits, however, come challenges in the effort to assure safety, security, and reliability for microgrids, utilities, and consumers alike. One of the considerations in designing the capabilities of the smart grid is the integration of supervisory control and data acquisition (SCADA) systems to allow a utility to remotely monitor and control network devices as a means of achieving reliability and demand efficiencies for utility sectors. Communication technologies in smart grid with renewable energy sources are explored.

ABBREVIATIONS

CANbus	Controller area network
CB	Circuit breakers
CT	Current transformer
DA	Distribution automation
DAC	Data acquisition computer server
DC/AC	Direct current/alternating current
DCS	Distributed control systems
DMS	Distribution management system
DNP	Distributed network protocol
EMS	Energy management system
FC	Fuel cell
FEP	Front-end processors
FG	Full graphics
Fieldbus	A family of industrial computer network protocols
GUI	Graphical user interface
HMI	Human-machine interface
HPS	Hybrid power system
I/O	Input/output
IEDs	Intelligent electronic devices
LAN	Local area network
LonWorks	Local operating network; a networking platform
MAS	Multiple address radio system
Modbus	A serial communications protocol originally published by Modicon (now Schneider Electric)
MPPT	Maximum power point tracking
OLE	Object linking and embedding

OPC	OLE for process control
PCS	Process control systems
PEM	Proton exchange membrane
PLC	Programmable logic controllers
PLC	Power line carrier
Profibus	Process field bus; a standard for fieldbus communication
PV	Solar photovoltaic generation
RAID	Redundant array of independent disks (hard disk storage system)
RES	Renewable energy sources
RTU	Remote terminal unit
SCADA	Supervisory control and data acquisition
SG	Smart grid
SOC	State of charge
SOFC	Solid oxide fuel cells
TCP/IP	Transmission control protocol/Internet protocol
THD	Total harmonic distortion
VT	Voltage transformer
WAN	Wide area network

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