1

Introduction to Smart Power Systems

Sivaraman Palanisamy[1], *Zahira Rahiman*[2], *and Sharmeela Chenniappan*[3]

[1] *World Resources Institute (WRI) India, Bengaluru, India*
[2] *Department of Electrical and Electronics Engineering, B.S. Abdur Rahman Crescent Institute of Science & Technology, Chennai, India*
[3] *Department of Electrical and Electronics Engineering, Anna University, Chennai, India*

1.1 Problems in Conventional Power Systems

The conventional power system is generally classified as power generation, power transmission, and power distribution systems. The power is generated from thermal plants, nuclear plants, or hydroplants at remote locations and this is transmitted to the load center through a power transmission system [1]. The distribution system is used to distribute the electric power to various end-users. It has limited control and visibility of power flows from generation to the end user's load. Some of the problems associated with conventional systems are limited visibility in power flows, limited control, delay in measurement and control, higher energy losses in transmission and distribution systems, poor power quality, etc. [2].

1.2 Distributed Generation (DG)

The distributed generation (DG) is used to produce the electric power closer to the load center or end-user loads to reduce the energy loss in the transmission as well as distribution system and improve the voltage profile. The sources of DG can be both renewable energy sources (like solar, wind, and fuel cells), and nonrenewable energy sources (like diesel generators). These sources as simply called distributed energy resources (DERs) [3]. Generally, these DGs are interconnected with the primary or secondary distribution systems based on their rating. Figure 1.1 shows the single-line diagram of a 100 kW rooftop solar PV system as DG connected to the 415 V, 50 Hz secondary distribution system.

Figure 1.2 shows the single-line diagram of a 1 MW rooftop solar PV system as DG connected to the 11 kV, 50 Hz primary distribution system.

The intermittency is one of the major challenges of using renewable energy sources such as solar PV and wind energy conversion systems as DG. Due to intermittence, the output power from the solar PV system and wind energy conversion system also varies throughout the operation resulting in power balance and stability issues [4]. The impact of intermittency can be reduced to a certain extent by using a complex software program/tool to predict the energy output based on various historical data.

Artificial Intelligence-based Smart Power Systems, First Edition.
Edited by Sanjeevikumar Padmanaban, Sivaraman Palanisamy, Sharmeela Chenniappan, and Jens Bo Holm-Nielsen.

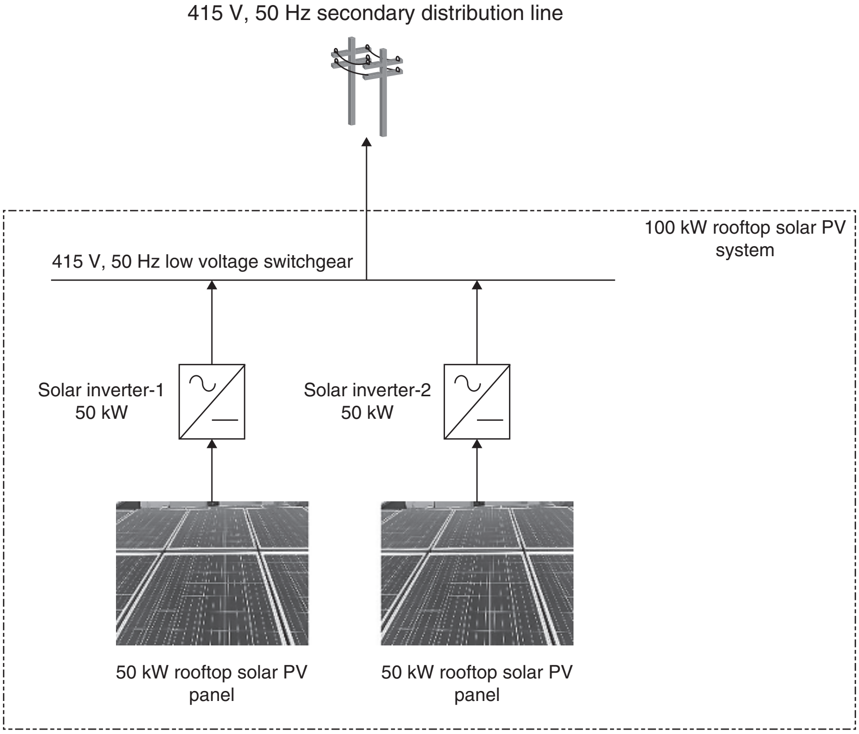

Figure 1.1 Single line diagram of a rooftop solar PV system connected to the secondary distribution system.

1.3 Wide Area Monitoring and Control

Power grids are the most complicated and essential systems in today's life. The risk of experiencing a wide variety of faults and failures is increasing [5]. The unpredictable and cascaded events of faults lead to a blackout, and they have an impact on a large range of consumers. Many grid codes allow the frequency within the specified tolerance limits. Hence, flexibility in frequency leads to under drawl or over drawl of real power, as well as under generation or over a generation by the utilities. This results in the overloading of transmission lines and under voltage or over voltage of the grid. Also, unpredictability, intermittency, and variability of renewable energy integration pose challenges in grid operation. Conventional Supervisory Control and Data Acquisition (SCADA) systems are limited to steady-state measurements and cannot be used for observing the system dynamics behavior. To overcome the drawbacks of a conventional system, one of the most recent advancements in modern power grids is wide-area monitoring (WAM). With the developments of WAM, power system dynamic behavior is monitored closely in real-time. So that the faults in the power grid can be identified and protected in a wider range [6].

The overall goal of using WAM is to improve protection and to develop new protection concepts that will make blackouts less probable and much less severe even if they do occur. The following are the key areas where WAM can help to protect power systems.

1. Dealing with large-scale interruptions
2. Taking the appropriate precautions to mitigate the impact of failed systems
3. Ignoring relay settings that are incompatible with the current system configuration
4. Achieving a reasonable balance between security and dependability

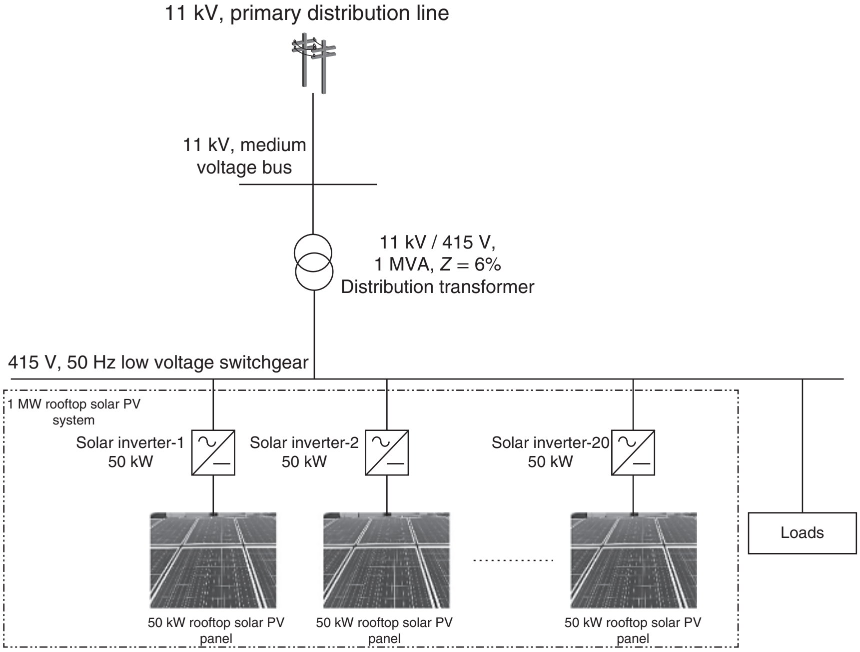

Figure 1.2 Single line diagram of a rooftop solar PV system connected to the primary distribution system.

The purpose of protection is to safeguard specific elements of the power system as well as the security of the power system as a whole.

In the case of main equipment protection, WAM plays a significant role. This is due to the fact that primary protection must consistently offer a very fast response to any failure on the element that it safeguards. WAM, on the other hand, can be a beneficial tool for increasing system performance due to the slower response time necessary for backup protection and the fact that it protects a zone of the system. Wide-area measurements have the potential to enable the development of supervisory methods for backup protection, more complex types of system protection, and altogether new protection concepts. Examples of these protection functions are

1. Dynamic relays adjust their parameters in response to changes in the system condition.
2. Multiterminal line protection has been improved.
3. Predictive end-of-line protection, which monitors the distant location breaker and replaces the under-reaching Zone 1 with an instantaneous characteristic if it is open.
4. Modify relay settings temporarily to prevent malfunction during cold load pickup.
5. Employ the capability of modern relays to self-monitor to find hidden faults and use the IEC 61850 hot-swap capabilities to eliminate them.
6. Artificial controlled microgrids provide an adaptive controlled divergence to prevent an uncontrolled system separation.

WAM gathers data from remote places throughout the power grid and integrates them in real-time into a single snapshot of the power system for a given time. Synchronized measurement technology (SMT) is a crucial component of WAM because it allows measurements to be correctly timestamped, typically using global positioning system (GPS) timing signals. The data may be simply merged with these timestamps, and phase angle measurements can be made with a common reference [7]. Figure 1.3 shows the generic WAMS architecture based on phasor measurement units (PMUs). PMUs, phasor data concentrators (PDCs), communication networks, data storage, and application software are the primary components of WAM. The number of substation PDCs is determined

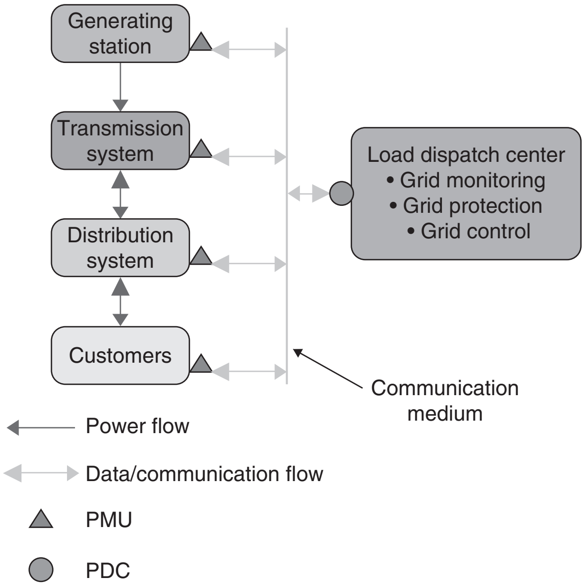

Figure 1.3 Block diagram of wide-area monitoring and control.

by the power system requirements. Voltage, current, and frequency are measured by PMUs placed in substations. These readings are routed straight to the central PDC or a substation PDC.

The following functions are available at the PDC substation:

- ✓ Synchronization of date and time
- ✓ Gathers info from PMUs
- ✓ Analyzes collected data
- ✓ Data is sent to the central PDC
- ✓ Communicates data with the regional SCADA
- ✓ Data is archived locally
- ✓ Carries out local data analysis and security actions

1.4 Automatic Metering Infrastructure

The name Advanced Metering Infrastructure or simply AMI refers to the entire infrastructure, which includes everything from smart meters to two-way communication networks to control center equipment, as well as all the applications that allow for the gathering and transfer of energy usage data in real-time. The backbone of the smart grid [8] is AMI, which enables two-way connectivity with customers. Error-free meter reading from remote, network problem and its diagnosis, load profile/patterns, energy audits/consumptions, and partial load curtailment in place of load shedding are all potential objectives of AMI. The typical building blocks of AMI are shown in Figure 1.4.

AMI is made up of several hardware and software components that all work together to measure energy consumption and send data about it to utility companies and customers [8]. The key technological components of AMI are,

- ☐ **Smart Meters**: Advanced meter devices that could gather data of electrical parameters at various intervals and transfer the data to the utility via fixed communication networks, as well as receiving information from the utility such as pricing signals and relaying it to the consumer [9].

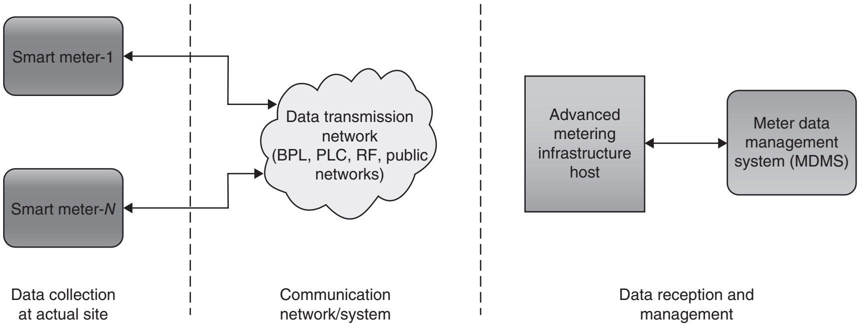

Figure 1.4 Basic building blocks of AMI.

- **Communication Network**: Smart meters can provide data to utility companies and vice versa. The advanced communication networks allow two-way communication between smart meters and utility companies. For these applications, networks like Broadband over Powerline (BPL), Power Line Communications (PLC), Fiber Optic Communication, Fixed Radio Frequency (RF), or public networks (e.g. landline, cellular, paging) are used [10].
- **Meter Data Acquisition System**: Data is collected from smart meters over a communication network and sent to the meter data management system (MDMS) using software applications on the Control Centre hardware and DCUs (Data Concentrator Units).
  MDMS Metering: receives the information, stores it, and analyzed it by the host system.

☐ **Home Area Network (HAN)**: It can be a consumer-side extension of AMI, allowing for easier communication between household appliances and AMI, and thus better load control by both the utility and the consumer [11].

The benefits of AMI are multifold and can be generally categorized as follows:

Operational Benefits: The entire system benefits from AMI since it improves meter reading accuracy, detects energy theft, and responds to power outages while removing the need for an on-site meter reading.

Financial Benefits: Utility companies financially benefit from AMI because it lowers equipment and maintenance costs, enables faster restoration of electric service during outages, and streamlines the billing process.

Customer Benefits: Electric customers benefit from AMI because it detects meter faults early, allows for speedier service restoration, and improves billing accuracy and flexibility. AMI also offers time-based tariff choices, which can help consumers save money and better manage their energy usage.

Security Benefits: AMI technology allows for better monitoring of system resources, reducing the risk of cyber-terrorist networks posing a threat to the grid.

In spite of various advantages, AMI deployment faces three significant challenges: higher capital costs or investments, connection or interoperability with other grid systems, and standardization.

High Capital Costs: A full-scale implementation of AMI necessitates investments in all hardware and software components, including smart meters, network infrastructures, and network management software, as well as costs associated with meter installation and maintenance.

Integration: Customer Information Systems (CISs), Geographical Information Systems (GISs), Outage Management Systems (OMSs), Work Management System (WMS), Mobile Workforce Management (MWM), SCADA/DMS, Distribution Automation System (DAS), and other utilities' information technology systems essentially integrated with AMI.

Standardization: Compatibility standards must be created, as they are the keys to properly connecting and sustaining an AMI-based grid system. They set universal requirements for AMI technology, deployment, and general operations.

Investing in AMI to modernize the power grid system will alleviate several grid stresses caused by the rising power demands. AMI will improve three critical aspects of power grid infrastructure such as system reliability, energy cost, and electricity theft.

System Reliability: AMI technology increases electricity distribution and overall dependability by allowing electricity distributors to identify and respond to electric demand automatically, reducing power outages.

Energy Costs: Increased stability and functionality, as well as fewer power outages and streamlined billing operations, will greatly reduce the expenses involved with providing and maintaining the grid, resulting in significantly cheaper electricity bills.

Electricity Theft: Electricity theft is a prevalent problem in Society. AMI systems that track energy usage will aid in monitoring power in real-time, resulting in enhanced system transparency.

1.5 Phasor Measurement Unit

A phasor measurement unit or simply PMU is a crucial measurement tool that is used on electric power systems to improve grid operators' visibility on the huge power grid network/system [12]. It measures the parameter called a phasor and it provides the information/data of magnitude and phase angle of voltage or current at a particular location [13]. This information/data shall be used to find the operating frequency at a particular time instant and examine the condition of the system as shown in Figure 1.5.

A PMU may provide up to 60 measurements per second. As compared with a typical SCADA-based system, the measurements per second are higher in PMU. A typical SCADA-based system will provide the data (one measurement data in two to four seconds time interval) [14]. The main advantage of using PMU over conventional SCADA system is PMU can collect the data of all PMU at a particular time through GPS. This means, that collected data across the power grid are time-synchronized. Because of this reason, PMUs are also called synchro phasors [15].

The information collected from the PMU conveys to the system operator whether the main electrical parameters such as voltage, current, and frequency are within the specified limit with tolerance or not. The capability of the PMU is as follows,

- Line congestion: prediction, analysis, and manage
- Analyzing the event after the disturbance or fault (post fault analysis)
- Instability and stress detection
- Inefficiencies detection

In this decade, several thousands of PMUs are successfully installed and commissioned in transmission and/or distribution grids across the globe. A PMU can be integrated with smart controllers, and this will reduce the manual operations required by the SCADA system in decision making and control. Due to this feature, the grid becomes robust and efficient, it allows the more integration of renewable powers, DERs, and microgrids.

The report on Unified Real-Time Dynamic State Measurement (URTDSM) by Power Grid Corporation of India Ltd. (PGCIL) shows the importance of PMU data (data from various lines at time-stamped) is useful for prediction and post fault event analysis. PGCIL followed the philosophy stated below for installing the PMUs across India, installation of PMUs on substations at 400 kV level above, all generating stations at 220 kV level and above, HVDC terminals, important inter-regional connection points, inter-national connection points, etc. Also, the provision of PDC at all State Load Dispatch Centers (SLDCs), Regional Load Dispatch Centers (RLDCs), and National Load Dispatch Center (NLDC) [7].

The PMU is used to measure the magnitude and phase angle of bus voltage and line current phasor. PMU takes the bus PT input for voltage and line CT input for current at the substation as well as GPS time signal. The PMU presently available in the market can measure one set of bus voltage (three-phase) and two sets of line current (three-phase). The typical arrangement of PMU in substation and Main Phasor Data Concentrator (MPDC)/Sub Phasor Data Concentrator (SPDC) in load dispatch center is shown in Figure 1.6 [7].

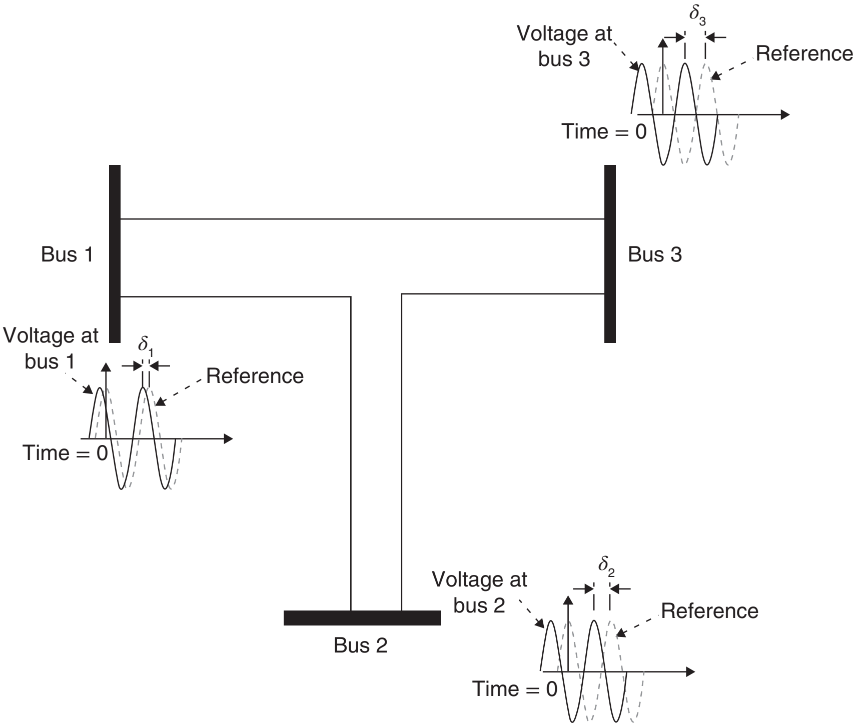

Figure 1.5 Transmission line data.

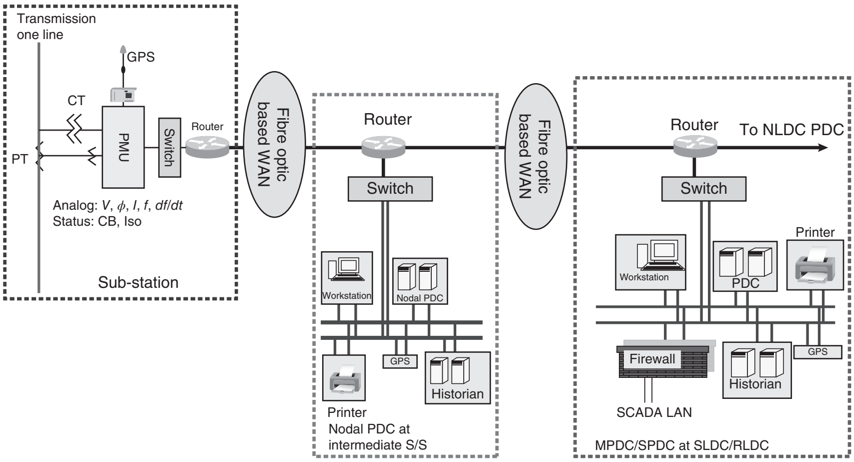

Figure 1.6 Typical arrangement of PMU in substation and PDC in the load dispatch center.

The PMU output from the substation is communicated to PDC through a Local Area Network (LAN) switch and router. A PDC at the load dispatch center is used to receive the data from the multiple PMUs of different substations. Also, PDC communicates with other PDCs and transfers the data. The PDCs align/store the PMU data by the time-stamped label and create the time-synchronized dataset. All the PDCs are connected locally with computers/host workstations, printers, and operators' cabinets via Ethernet.

1.6 Power Quality Conditioners

The IEEE Std 1100-2005 [16] defines the power quality as the concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment. The IEEE Std 1159-2019 [17] categorizes the various power quality phenomena which are transients, short-duration RMS variation, long-duration RMS variation, imbalance, waveform distortion, voltage fluctuations, and power frequency variations [17, 18].

The power quality conditioners like Distribution STATCOM (DSTATCOM), Dynamic Voltage Restorer (DVR), and Unified Power Quality Conditioners (UPQCs) are widely used for dynamic reactive power compensation, voltage profile (voltage sag and swell, under-voltage and over-voltage) enhancement during the fault or other events. These power quality conditioners inject dynamically controlled reactive power to enhance the voltage profile.

The harmonics are one of the important power quality parameters and they are generally defined as the deviation of voltage and/or current from ideal sinusoidal waveshape due to non-linear characteristics of the connected loads and power electronics (inverter) based generations. IEEE Std 519-2014 IEEE recommended practice and requirements for harmonic control in electric power systems and provided the recommended harmonic limits for both voltage and current at the point of common coupling. If the harmonic injection from the plant exceeds the recommended limits specified in IEEE 519, suitable mitigation measures (e.g. harmonic filters) shall be proposed and tuned to mitigate the harmonics propagation into the power systems [19].

Various types of harmonic filters are available in the market for harmonic mitigation. They are passive filter, active filter, and hybrid filter. Passive filters are one of the cheaper and cost-effective solutions for harmonic mitigation [16]. It contains passive elements such as resistors, capacitors, and inductors. Based on the characteristics, passive filters are further classified into the low-pass filter, high-pass filter, band-pass filter, and tuned filters. The low pass filter is used to cancel the higher-order harmonics, while the high-pass filter is used to cancel the lower-order harmonics. A band-pass filter is used to cancel the order or frequency of the harmonic outside the range of band frequency. The tuned filters are used to cancel one specific harmonic order or frequency.

Shunt Active Power Filter is used to mitigate the current harmonics propagation into the system, reactive power compensation as well as balance the unbalanced currents. It injects the equal compensating currents with a 180° opposite phase shift for harmonic cancelation. This can also be used for voltage profile enhancement and reactive power compensation. It employs the micro-controller-based control circuits to estimate the magnitude of harmonic contents of each order [19–22]. The active filter is expensive as compared with passive harmonic filters and it is suitable for the place where plant loading pattern varies with respect to time [23].

A hybrid filter is a combination of both passive and active harmonic filters. It has the combined characteristics of both passive and active harmonic filters. The passive part of the filter is used for mitigation of harmonic current injected by the loads which are operating constantly throughout the day and the active harmonic filter is used to mitigate the harmonic currents injected by the loads whose operations vary with respect to time [24]. The hybrid filter is economic as compared with the active harmonic filter of the same rating. This filter is suitable for the locations where partial loads are constant throughout their operation and partial loads vary with respect to time.

1.7 Energy Storage Systems

The energy storage systems (ESSs) are widely used to store the energy whenever the surplus power is available/the cost of electricity is low and discharge the stored energy during the scarcity/cost of electricity is high. Concerns about the environment, such as global warming, have become global issues. As a result, the use of renewable energy sources like solar and wind power, as well as Smart Grids that effectively use all sorts of power sources, is seen as a very promising technology [25]. Electricity grids achieve reliable power supply by balancing supply and demand to the best of their abilities. However, when the use of solar power and other renewable energy sources, which have variable production, grows, the grid's power supply may become unstable [26]. This poses several difficulties. To overcome such difficulties, an ESS has been required in the power system [27]. In an emergency, energy storage devices can also be used as a backup power supply [28]. ESSs are extremely adaptable, and they may be used to satisfy the needs of a wide range of customers and in a variety of industries [29, 30]. These include renewable energy power producers, grid equipment such as transmission and distribution equipment, as well as commercial buildings, factories, and residences [31].

The grid-connected ESSs are used for both energy management applications and power quality applications such as load balancing or leveling, reducing the intermittency and smoothing the renewable energy integration, peak demand shifting or shaving, and providing the uninterrupted power supply to end-user loads, voltage and frequency regulation, voltage sag mitigation, reactive power control, and management, black start and islanded mode of operation, Volt/var control, etc. in the power systems [32]. The amount of renewable energy penetration keeps increasing every year which demands the requirements of grid-connected ESSs. The ESS is used to smooth the power output from renewable energy sources such as solar PV and wind energy conversion systems and level the load pattern.

The ESS can be classified in many ways, but one of the most useful is one based on the duration and frequency of power delivery. They are (i) short-term (seconds to minutes), (ii) medium-term (day storage), and (iii) long-term ESS (weekly to monthly) [33].

The short-term ESS (less than 25 minutes) [33] shall be used for spinning reserve, peak shaving, UPS, primary and secondary frequency control, electric vehicles (EVs), etc.

The medium-term ESS (1–10 hours) [33] shall be used for load leveling, tertiary frequency control, UPS, tertiary frequency control, etc.

Finally, the long-term ESS (from 50 hours to less than three weeks) [33] shall be used for long-term services during periods whenever power output from renewable power plants (solar and wind) is limited (known as "dark-calm periods").

The short-term services possibly will be provided via flywheels, superconductive magnetic coils, and super-capacitors. The medium-term services possibly will be provided by pumped hydropower, compressed air ESS, thermoelectric storage, and electrochemical ESS, such as lithium-ion, lead-acid, high temperature, and flow batteries [34, 35]. Hydrogen or natural gas storage systems can provide long-term services.

1.8 Smart Distribution Systems

The electric power distribution systems are used to distribute the electric power to end customers designed to deliver power from substations to customers. In order to operate the end user's equipment to an efficient and satisfactory level, the incoming power supply from the distribution company shall have high reliability and quality. Nowadays, end-users are using sophisticated equipment for easy control of their applications. This sophisticated equipment requires a high-quality and reliable input power supply for their trouble-free day-to-day operations [36]. In order to provide a high-quality and reliable power supply, the conventional distribution systems are changed as smart distribution systems with additional devices or equiment's and technology in place. The faults are one of the major problems in the distribution system and affect the incoming power supply to end-users until the fault is rectified. The majority of the faults are transients in nature. Hence, the auto recloser is used to close the circuit after the fault incident with the intended time delay. This auto recloser function reduces the human intervention to switch ON the circuit breaker manually after the fault. Also, fault identification sensors are used to easily identify the faults which are permanent in nature. The use of fault identification sensors reduces the time and effort required to examine the fault location through physical inspection.

Another important problem concerning the conventional distribution system is the lack of remote monitoring and control, and grid automation capability [2]. In smart distribution, these features are included and the distribution operator at the control center or central monitoring and control location can easily monitor what is happening in the grid and promptly take the necessary actions in case of any extreme faults/events. Modern intelligent devices, smart grid applications like WAMS, and distribution PMUs are improved the distribution system monitoring and controllability functions.

The DG is used to produce the energy locally closer to the end-user loads. It reduces the energy losses in the distribution lines. The DG uses DERs which are available closer to end-users like solar PV systems, wind energy conversion systems, and fuel cells for power generation. The main problems of solar PV systems and wind energy conversion systems are uncertainties and variable output power [37]. The ESSs are used to smooth the output power from the renewable energy systems. Nowadays, smart distribution system employs the distributed ESSs connected across the distribution system to smooth the output power from DERs like solar PV systems.

The recent development and advancement in multi-disciplinary engineering are EVs. EVs are emerging in this decade due to the rapid depletion of fossil fuels and environmental pollution. These EVs are charged by means of an electric power supply from the distribution system. The charging characteristics of EVs are not uniform and vary with respect to the state of charge of the battery [38]. The large penetration of these EVs on the distribution system shall change the loading pattern of the distribution system.

1.9 Electric Vehicle Charging Infrastructure

The EVs are an alternative to conventional internal combustion engine-based vehicles. Nowadays, the usage of EVs is rapidly increasing and will be connected and recharged across the distribution systems. The EV charging infrastructure or electric vehicle supply equipment (EVSE) is used to recharge the batteries of EVs. In the smart distribution system, EVSE is the main component of the EVs ecosystem. It is essential to revamp the existing electric distribution infrastructure with modern technologies and equipment to cater to the large penetration of EV loads [39]. Hence, the necessary planning action to be taken care of and the upgradation of existing electrical infrastructure or new electrical infrastructure is required at different levels.

The power rating of EV chargers is very based on vehicle type (two-wheelers, three-wheelers, and four-wheelers) and type of charging (slow charging and fast charging). The typical rating of an EV charger is in the range of 500 watts (W) to 500 kW.

Based on the location of the charging unit (EVSE), EV charging is classified into an Onboard charger and OFF-board charger. If EVSE is placed inside the vehicle, then it is called an Onboard charger, i.e. charging units are kept within the vehicle. If the EVSE is placed outside the vehicle, then it is called an Off-board charger, i.e. charging units are kept outside the vehicle.

Based on the physical location of charging, EV charging is further classified into residential charging and public charging. The EV owners or users charging their vehicles in their residential homes is called residential charging. The advantage of residential charging is the lesser cost per energy usage in kWh and the disadvantage is taking more time (in the range of five to eight hours) for recharging. On the other hand, public charging stations are used for commercial vehicles. Most public charging station employs fast chargers for recharging commercial vehicles in a lesser time duration [40].

Due to technological advancement, nowadays Vehicle to Grid (V2G) concept becomes more popular. In this V2G concept, the stored energy available in the vehicle is again fed back to the grid during peak hours as a distributed ESS.

1.10 Cyber Security

Cyber security is one of the key features of smart power systems. It is used to improve service reliability. Hence, it is brought into the power system in the planning and development stage itself. It ensures the legacy of security and protection of data. The highly secured data can be achieved from a properly planned strategy, and it provides flexibility in operation and efficiency. The utilities should implement a comprehensive, integrated, well-monitored, and regularly updated cyber security program [41]. Cyber security is essential for the various elements of smart power systems such as smart meters, SCADA systems, substations, and control systems, and cyber security actions are applied to all the participants of power systems, i.e. generating station, transmission system, and distribution systems.

1.11 Conclusion

The conventional power system has limited power-generation plants or sources connected to the bulk transmission grid and it powers the millions of end-users across it. It has limited control and visibility of power flows from generating plants to the end-users. This chapter discussed the various technological developments and recent advancements such as DG, WAM, and control using automatic metering infrastructure, PMU, power quality conditioners, EV charging infrastructure, smart distribution systems, and ESSs, and cyber security in smart power systems.

References

1 Sivaraman, P., Sharmeela, C., Mahendran, R., and Thaiyal Nayagi, A. (2020). *Basic Electrical and Instrumentation Engineering*. Wiley.

2 Sivaraman, P. and Sharmeela, C. (2020). Existing issues associated with electric distribution system. In: *Handbook of Research on New Solutions and Technologies in Electrical Distribution Networks* (ed. B. Kahn, H.H. Alhelou and G. Hayek), 1–31. Hershey, PA: IGI Global.

3 Pandey, S.K., Mohanty, S.R., and Kishor, N. (2013). A literature survey on load–frequency control for conventional and distribution generation power systems. *Renewable and Sustainable Energy Reviews* 25: 318–334.

4 Sharmeela, C., Sivaraman, P., Sanjeevikumar, P., and Holm-Nielsen, J.B. (2021). *Microgrid Technologies*. Wiley.

5 Leger, A.S., Spruce, J., Banwell, T. et al. (2016). Smart grid testbed for wide-area monitoring and control systems. In: *2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, 1–5. IEEE.

6 Malik, H., Ahmad, M.W., Alotaibi, M.A., and Almutairi, A. (2022). Development of wide area monitoring system for smart grid application. *Journal of Intelligent & Fuzzy Systems* 42 (2): 827–839.

7 Unified Real-Time Dynamic State Measurement (URTDSM) Report (2012). Power Grid Corporation of India Ltd Gurgaon Feb'12. PGCIL, https://cea.nic.in/wp-content/uploads/2020/03/1st-1.pdf (accessed 14 September 2022).

8 Jaiswal, D. and Thakare, M. (2022), Overview of an Advanced Metering Infrastructure Based on Smart Meters (Feb 26, 2022). *Proceedings of the 3rd International Conference on Contents, Computing & Communication (ICCCC-2022)*, Available at SSRN: https://ssrn.com/abstract=4056050 or http://dx.doi.org/10.2139/ssrn.4056050.

9 Martins, J.F., Pronto, A.G., Delgado-Gomes, V., and Sanduleac, M. (2019). Smart meters and advanced metering infrastructure. In: *Pathways to a Smarter Power System* (ed. A. Tascikaraogu and O. Erdinc), 89–114. Academic Press.

10 Ghasempour, A. (2016). Optimum number of aggregators based on power consumption, cost, and network lifetime in advanced metering infrastructure architecture for smart grid internet of things. In: *2016 13th IEEE Annual Consumer Communications & Networking Conference (CCNC)*, 295–296. IEEE.

11 Rahmann, C. and Alvarez, R. (2022). The role of smart grids in the low carbon emission problem. In: *Planning and Operation of Active Distribution Networks*, 455–485. Cham: Springer Lecture Notes in Electrical Engineering book series (LNEE, volume 826).

12 Hampannavar, S., Teja, C.B., Swapna, M. et al. (2020). Performance improvement of M-class phasor measurement unit (PMU) using hamming and blackman windows. In: *2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020)*, 1–5. IEEE.

13 Sodhi, R., Srivastava, S.C., and Singh, S.N. (2011). Multi-criteria decision-making approach for multistage optimal placement of phasor measurement units. *IET Generation, Transmission and Distribution* 5 (2): 181–190.

14 Narendra, K., Gurusinghe, D.R., and Rajapakse, A.D. (2012). Dynamic performance evaluation and testing of phasor measurement unit (PMU) as per IEEE C37. 118.1 Standard. In: *Doble Client Committee Meetings International Protection Testing Users Group,* (PTUG), Chicago, IL, USA, vol. 10.

15 Roscoe, A.J. (2013). Exploring the relative performance of frequency-tracking and fixed-filter phasor measurement unit algorithms under C37. 118 test procedures, the effects of interharmonics, and initial attempts at merging P-class response with M-class filtering. *IEEE Transactions on Instrumentation and Measurement* 62 (8): 2140–2153.

16 IEEE Standards Association. (2005). IEEE Std1100-2005-IEEE recommended practice for powering and grounding electronic equipment. In *Institute of Electrical and Electronics Engineers*.

17 "IEEE Recommended Practice for Monitoring Electric Power Quality," in *IEEE Std 1159-2019 (Revision of IEEE Std 1159-2009)*, 1–98, 13 August 2019, https://doi.org/10.1109/IEEESTD.2019.8796486.

18 Sivaraman, P. and Sharmeela, C. (2021). Power quality and its characteristics. In: *Power Quality in Modern Power Systems* (ed. P. Sanjeevikumar, C. Sharmeela and J.B. Holm-Nielsen), 1–60. Academic Press.

19 Sivaraman, P. and Sharmeela, C. (2021). Power system harmonics. In: *Power Quality in Modern Power Systems* (ed. P. Sanjeevikumar, C. Sharmeela and J.B. Holm-Nielsen), 77–85. Academic Press.

20 Mahendran, R., Sivaraman, P., and Sharmeela, C. (2015). Three phase grid interfaced renewable energy source using active power filter. In: *5th International Exhibition & Conference, GRIDTECH 2015*, 77–85. New Delhi, India.

21 Singh, B., Al-Haddad, K., and Chandra, A. (1999). A review of active filters for power quality improvement. *IEEE Transactions on Industrial Electronics* 46 (5): 960–971.

22 Patel, M.A., Patel, A.R., Vyas, D.R., and Patel, K.M. (2009). Use of PWM techniques for power quality improvement. *International Journal of Recent Trends in Engineering* 1 (4): 99–102.

23 Kale, M. and Ozdemir, E. (2005). Harmonic and reactive power compensation with shunt active power filter under non-ideal mains voltage. *Electric Power Systems Research* 74 (3): 363–370.

24 Akagi, H. (1996). New trends in active filters for power conditioning. *IEEE Transactions on Industry Applications* 32 (6): 1312–1322.

25 Baker, J.N. and Collinson, A. (1999). Electrical energy storage at the turn of the millennium. *Power Engineering Journal* 13 (3): 107–112.

26 Sivaraman, P., Sharmeela, C., and Kothari, D.P. (2017). Enhancing the voltage profile in distribution system with 40 GW of solar PV rooftop in Indian grid by 2022: a review. In: *1st International Conference on Large Scale Grid Integration Renewable Energy*, September 2017 in New Delhi, India.

27 Lawder, M.T., Suthar, B., Northrop, P.W.C. et al. (2014). Battery energy storage system (BESS) and battery management system (BMS) for grid-scale applications. *Proceedings of the IEEE* 102 (6): 1014–1030.

28 Chen, H., Cong, T.N., Yang, W. et al. (2009). Progress in electrical energy storage system: a critical review. *Progress in Natural Science* 19 (3): 291–312.

29 Feehally, T., Forsyth, A.J., Todd R. et al. (2016). Battery energy storage systems for the electricity grid: UK research facilities. In: *The 8th IET International Conference on Power Electronics, Machines and Drives (PEMD) 2016*. IET Power Electronics, Machines and Drives 2016, 19–21 April 2016, Glasgow, UK. Institution of Engineering and Technology. ISBN 978-1-78561-188-9, https://doi.org/10.1049/cp.2016.0257.

30 Gallardo-Lozano, J., Milanés-Montero, M.I., Guerrero-Martínez, M.A., and Romero-Cadaval, E. (2012). Electric vehicle battery charger for smart grids. *Electric Power Systems Research* 90: 18–29.

31 Xu, X., Bishop, M., Oikarinen, D.G., and Hao, C. (2016). Application and modeling of battery energy storage in power systems. *Journal of Power Energy System* 2 (3): 82–90.

32 Sivaraman, P. and Sharmeela, C. (2017). Battery energy storage system addressing the power quality issue in grid connected wind energy conversion system. In: *1st International Conference on Large-Scale Grid Integration Renewable Energy in India*, 1–3. New Delhi, India.

33 EmilioGhiani, G.P. (2018). Impact of renewable energy sources and energy storage technologies on the operation and planning of smart distribution networks. In: *Operation of Distributed Energy Resources in Smart Distribution Networks* (ed. K. Zare and S. Nojavan), 25–48.

34 Wang, G., Konstantinou, G., Townsend, C.D. et al. (2016). A review of power electronics for grid connection of utility scale battery energy storage systems. *IEEE Transactions on Sustainable Energy* 7 (4): 1778–1790.

35 Xavier, L.S., Amorim, W., Cupertino, A.F. et al. (2019). Power converters for battery energy storage systems connected to medium voltage systems: a comprehensive review. *BMC Energy* 1 (1): 1–15.

36 Sivaraman, P. and Sharmeela, C. (2020). Introduction to electric distribution system. In: *Handbook of Research on New Solutions and Technologies in Electrical Distribution Networks* (ed. B. Kahn, H.H. Alhelou and Ghassan), 1–31. Hershey, PA: IGI Global.

37 Eltawil, M.A. and Zhao, Z. (2010). Grid-connected photovoltaic power systems: technical and potential problems – a review. *Renewable and Sustainable Energy Reviews* 14 (1): 112–129.

38 Khalid, M.R., Alam, M.S., Sarwar, A., and Asghar, M.J. (2019). A comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid. *eTransportation* 1: 100006.

39 Sivaraman, P., Sharmeela, C., and Logeshkumar, S. (2021). Charging infrastructure layout and planning for plug-in-electric vehicles. In: *Cable Based and Wireless Charging Systems for Electric Vehicles: Technology, Control, Management and Grid Integration* (ed. P. Sanjeevikumar), 1–24. UK: IET.

40 Sivaraman, P. and Sharmeela, C. (2021). Power quality problems associated with electric vehicle charging infrastructure. In: *Power Quality in Modern Power Systems* (ed. I.S. Padmanaban, C. Sharmeela and J.B. Holm-Nielsen), 151–161. Academic Press.

41 Teymouri, A., Mehrizi-Sani, A., and Liu, C.C. (2018). Cyber security risk assessment of solar PV units with reactive power capability. In: *IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society*, 2872–2877. IEEE.