Chapter 17
Power Quality Issues in Smart Grid/Microgrid

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Abstract Microgrids and smart grids are emerging as the latest trending aspect in power industries. The smart grid integrates the technology dealing with Information and Communication in almost all aspects of power systems starting from electricity generation till consumption in order to improve the reliability of energy consumption and service, minimize the environmental impact, enable active participation of the consumers, new products and markets, improves the efficiency leading to more safe and reliable energy production and distribution. The other benefits include reducing carbon emission, supports the increased use of electric vehicles and creates wider opportunities for employment. Smart grids can be seen as a combination of microgrids and mini grids among which microgrid plays a major role in accomplishing authentic and more secure energy supply for retail load as well as distributed generation. On the other hand, microgrid can be seen as a decentralized energy system comprising distributed energy sources with demand management, storage and generations with loads which are capable of operating either in parallel or independently. Despite the benefits, smart grid as well as microgrids face several power quality-related issues and challenges which are to be met out in order to avail the entire benefits of this emerging technology. The challenges faced by the smart grid and microgrid can be categorized as two, viz., wide variations in power

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A. K. Bohre et al. (eds.), *Planning of Hybrid Renewable Energy Systems, Electric Vehicles and Microgrid*, Energy Systems in Electrical Engineering,
https://doi.org/10.1007/978-981-19-0979-5_17

quality which are unpredictable including, slow voltage changes, frequency deviations, harmonics, flicker and unbalance. Events including rapid voltage changes, dips, swells and interruptions. The disturbances and variations in power quality are mainly caused due to harmonic emission by power electronic devices, interference between power line carrier communication and devices, immunity of the devices and weakening of the transmission grid. This chapter aims to identify the root cause for the above-said power quality issues and challenges and investigation of various mitigation techniques.

Keywords Microgrid · Smart grid · Power quality

17.1 Introduction

The Smart Grid (SG) and microgrid (MG) power quality (PQ) problems are discussed in this chapter. Section 17.1.1 describes about the SGs, Sect. 17.1.2 explains the PQ challenges in SGs, Sect. 17.1.3 illustrates the PQ challenges in both AC and DC MGs. The flow of this chapter is as shown in the Fig. 17.1a

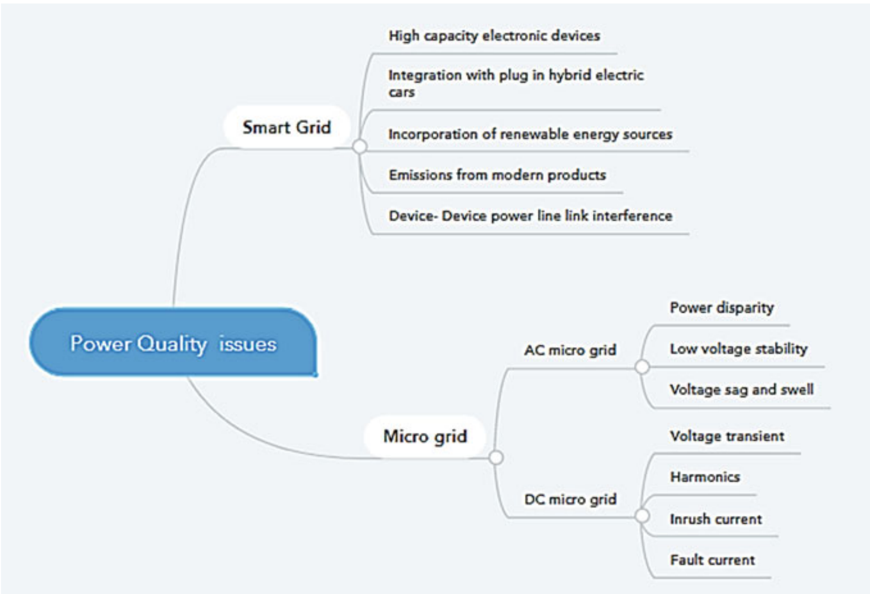


Fig. 17.1 A graphical representation of the chapter (**a**). **b** Block diagram of smart grid

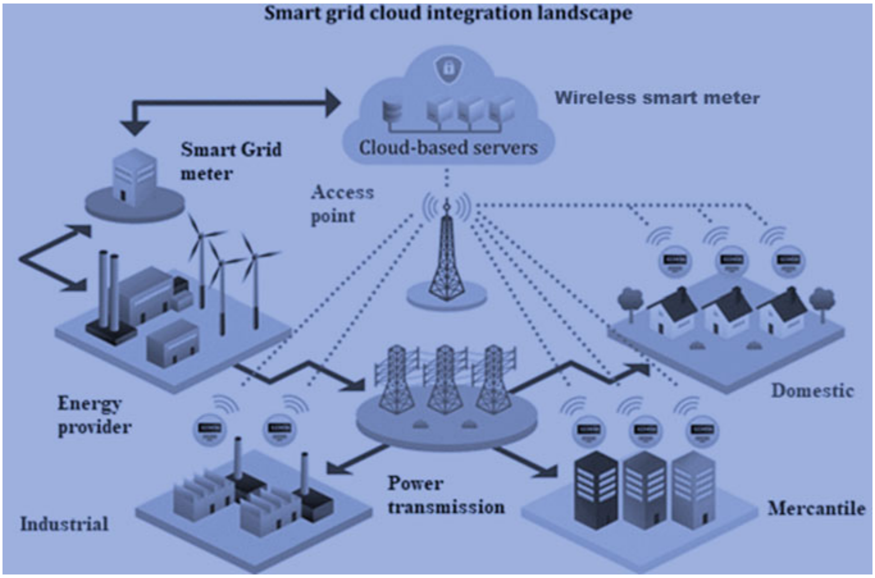


Fig. 17.1 (continued)

17.1.1 Smart Grid

- A SG is made up of claims focused on information that will allow for the seamless incorporation and advanced penetration of renewable energy. Accelerating the production and mainstream use of plug-in hybrid electric vehicles (PHEVs), in addition to their future use as grid storage, would be critical. It can be described in a variety of ways (Naderi et al. 2019):
- SG is a bright intelligent device that adds intelligence and networking capabilities to current electrical systems, such as automated metering technology, to increase the national grid's electricity efficiency.
- SG keeps track of the whole electricity chain, including transmission and delivery facilities from power plants to customers. For both consumers and utilities, it ensures advanced energy efficiency (EF). It reroutes traffic from peak hours to off-peak hours depending on goals (Gandoman et al. 2018).

However, a SG is a fully integrated grid. It will automatically react to changes in electrical parameters that are essential for the grid's smooth operation. Sensors, microcontrollers and other devices can assist with this.

Energy thefts can be stopped, correct power bills can be provided, clean energy can be encouraged, greenhouse emissions can be reduced and power losses can be reduced with the SG. The Internet age has also ushered in new developments in the power sector, with SGs now being created. It is the most recent generation of grids, using smart technologies.

SGs, in contrast to MGs, have automated knowledge and power, complex optimization of grid services, dispersed resources (similar to MGs or exactly smart MGs), request replies, request side capitals, EE possessions, smart monitoring scheme and distributed resources (like MGs or specifically smart MGs). Advanced electricity storage and smart incorporation (actual response and appropriate usage evidence). SGs also consume additional aids, faster safety, regulated auto healing, greater robustness, greater green energy, greater efficiency, higher PQ, greater re-configurability and a higher capacity factor (Jolhe et al. 2016).

Depending upon the concepts, a smart MG may be termed as a MG with some unique features that will boost the all-inclusive performance of the structure in order to sort it more environmentally efficient, gain maximum functionality by rising the energy intensity and increase the entire usage and value of current productions and transmission power. It may be utilized to rise the sources of renewable energy, boost EF to meet emerging modern demands and make the system more efficient, resilient, versatile, long-lasting and so on.

17.1.2 Power Quality Challenges in Smart Grid

SGs, like all other technologies, pose certain threats to conventional grids. Meantime, these often carry some novel techniques to boost the operations. The following paragraphs outline the major problems and resources that SGs can offer (Senthilkumar et al. 2015):

1. **High-capacity electronic devices**.
2. **Integration with plug-in hybrid electric cars**.
3. **Incorporation of renewable energy sources**.
4. **Emissions from modern products**.
   We expect development in distributed production (making at under voltage extents) and different modes of ingestion as a result of SG deployment (for instance, E-Vehicles accusing positions, extended large speed railways, etc.). Harmonic pollution is one of the PQ disruptions that some of these modern consumption devices produce. Below the frequency of 2 kHz, harmonics and inter-harmonics would be high. The release is low over the entire range above 2 kHz, where it is created through additional equipment such as energy effective drives, micro-mini generators and PV connections. It would be more difficult to quantify these small amounts of harmonics at advanced frequencies than it is now for higher levels and lower frequencies.
5. **Device-to-device and power line link interference**
   Phones, consumers, distributed generators and the grid operator would be able to communicate more easily with SGs. Because of its ease of availability, power line communication may seem to be an obvious alternative, but it could create new disruptions in the power grid, subsequently a further decrease in power efficiency. Diverged disruptions can occur relying on the incidence used for

power line communication, impeding with radio broadcasting and communication. Current strategies may hamper with power line announcement by causing an extraordinary degree of interference with the occurrence preferred for power line communication or through making a small impedance direction, essentially choosing out the signal.

6. **Increase in distorted Harmonic voltage**
   In SGs, demand volume would rise by equal development in output. Because of the continued increase in both construction and ingestion, the distorted harmonic voltage may suit unsatisfactorily high. Furthermore, the number of switching sequence may continue to rise, potentially reaching unsatisfactorily great levels. At the power system frequency, output and usage are in equilibrium, but not at harmonic frequencies.

With the above PQ concerns, it's tempting to believe it the proliferation of smooth grid technologies would exacerbate PQissues. However, here the other edge of the storey! Smooth grid expertise would aid at the reduction of PQ issues. They could only handle PQ if they could calculate it, the SG allows us to do so. Several elements of the SG work together to help utilities provide advanced excellence power to our house. Smooth metres on the supply grid aid in the management of voltage and power factor. Advanced energy metres, which are a core component of SG, provide both you and your utilities with more knowledge about the electricity supplied to your house. They have a capacitor, much like most modern gadgets, to step down the voltage for the digital electronics. To avoid interference with other electronic or networking devices, they are designed to follow stringent FCC (Federal Communication Commission) standards.

SG also guarantees that the systems connecting to it are switched and protected, resulting in network stability that is unrivalled. However, low PQ may have a significant effect on this, resulting in system malfunction and/or failure. SGs provide progressive Distributed Management System (DMS) applications such as PQ Analysis to address this. "Utilities may use Smart Grid technologies to improve service efficiency for each customer they support, resulting in a more reliable and accurate electricity supply."

SG also allows for the improvement (or prevention) of current power system output without the need for significant improvements in lines, wires, transformers and other infrastructure. Improvements may be made in terms of efficiency, voltage output or price from the customer's perspective. Figure 17.1b Shows the block diagram of SG, it could be implemented on commercial, industrial and residential, etc., is represented in the diagram.

A decrease in long-term voltage–magnitude variation is planned by rendered SG to the immediate imminent, which will increase voltage efficiency. The real-time data, utilities may practice SG technologies to improve supply efficiency for each customer they service, resulting in a more reliable and accurate power supply.

17.1.3 Microgrid

MGs are designed to provide electricity to a limited region. It's similar to supplying electricity to a rural location, a residential, government or industrial building in a community where the national grid is unavailable. The MG infrastructure is an insignificant supply system made up of output utilities and distributed energy supplies (DES) including sources of renewable energy (RE), co-generation, combined heat and power (CHP) generation, fuel cells and energy storage systems. A MG is a self-reliant electricity structure that covers a specific geographic area, such as a college campus, a hospital complex, a commercial district or a neighbourhood. MGs are driven by one or more types of distributed electricity (PV panels, wind system, shared heat and water, generators). Besides, several fresher MGs provide energy storage, mostly in the arrangement of batteries. Some now have charging points for hybrid vehicles. The MG, which is connected to nearby buildings, delivers electricity and potentially heat and cooling to its customers through sophisticated software and control systems. Figure 17.2 illustrates the applications of MG.

MGs come in a variety of shapes and sizes.

1. Institutional MGs and the campus climate.
2. MGs in the community.
3. MGs that are off-grid and off-the-grid.
4. MGs for military bases.
5. MGs for commercial and industrial (C&I) use.

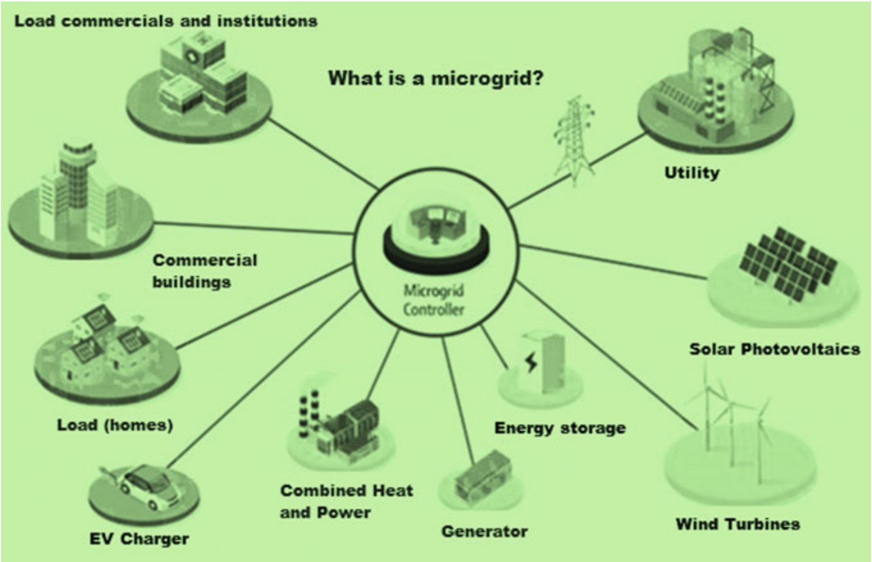


Fig. 17.2 Structure of microgrid

The combination of the erratic sort of Renewable Energy (RE) sources with progressive Power Electronics (PE) converter equipment causes a PQ problem. In addition, the existence of nonlinear and destabilizing loads in MG looks to have an effect on the PQ of the energy supply in the power delivery network.

In a (MG, three separate PQ problems are assessed: voltage decline, harmonic falsification and phase unbalance. An assorted-integer direct accumulation with harmonic load movements is proposed as a design for an energy storage procedure for MG. It has in charge of both optimizing the preparation of entire production, depository and properties of load, as well as resolving PQ problems in the tertiary extent of mastery by changing the extents of specific categories of loads inside the grid. On a theoretical experiment-case MG with housing, manufacturing and viable loads, this procedure is replicated for various situations. The findings show that the algorithm's demand-side control system will adjust the consumption behaviour of such loads effectively, ensuring that the voltage decrease, distortion in harmonic voltage and potential instability factor follow the necessary requirements in each MG node during the daytime. It is too worth noting that if energy price on the spot market rises, the MG will steadily decrease the amount of energy it buys after the efficacy grid to where it has connected.

17.1.4 Power Quality Subjects in Microgrid

A MG could work in both independent and grid-tied modes. It faces a PQ problem in both modes, where it is dissimilar together. AC MG and DC MG have also been proposed to alternatives in the literature. DC MGs have been shown to have properties that mitigate certain PQ issues. DC MG, on the other hand, has its own set of problems with power efficiency.

A. AC Microgrid Problems

An AC MG is a tiny grid structure that is associated to various kinds of distributed generators and loads. It's difficult to maintain grid reliability and power balancing with too many different types of generation and loads. There are a number of problems with AC MG. These are the problems:

i. voltage safety, ii. system reliability, iii. power output, iv. system security and control.

The following are few of the PQ problems in an AC MG:

1. **Power Disparity**

As the MG transitions from grid connected to disconnect method of action, there is a power imbalance. In grid-isolated mode, a separate micropower station connected to the MG provides electricity. Energy depository system is used to sustain power imbalances that exist throughout the MG's transformation time when these power stations have a sluggish dynamic reaction. As regular mode is restored, the phase series and voltage magnitude must be maintained in order to synchronize with the grid.

2. **Low-Voltage Stability**

Since power delivery support in distributed generation and MGs is smaller than in large grids, low-voltage stability issues arise. Since DGs and MGs are regulated by power converters, the power transmission in the converters is restricted in contrast with normal power plants. This type of converters has small energy than conventional systems at times of heavy grid demand. Traditional power plants have a lot of kinetic energy contained in their spinning turbines, so they can handle a lot of power during intermittent situations. When the huge grids are experiencing a power outage and the MG is switched to islanded approach, power-splitting care from the MG to the huge grid is nil. During the power blackout, the remote action will activate a disparity from the supply demand ratio, which will result at the grid's voltage outline being rejected.

3. When a MG experiences voltage sag or swell, the effectiveness of converter in power electronics, the distributed generation can suffer. Throughout sag periods, the grid-tied loads demand the reactive power and distributed generators based on power electronics converters attempt to inject reactive power, they encounter overcurrent in single or more phases. Another issue is an exceeding the extreme voltage cap, which could reason for the generators to trip and result in an outage.

B. Problems in DC MG

Many publications focus on PQ problems in AC MG systems, nonetheless slight consideration has given in PQ problems at DC MGs. In addition to consuming and supplying electricity to and from the grid, the DC MG can also run at grid-tied mode. It also operates in an isolated method of service. Imbalance in voltage of two-faced DC bus, voltage variations presents at the AC system, overflow current and harmonics in DC MG are some of the common PQ problems in DC MG (Ghetti et al. 2012).

1. **Voltage Transient**

This issues are common in AC MGs, nevertheless they also impact DC MGs. The key causes of voltage transients are capacitor bank swapping, distributed generation initialization and shutdown in a DC MG and load shift. The capacitor banks are used to switch so that the changes in voltage transfer from the low-voltage AC MG to DC MG through a rectifier reach up to 194 percent of the operating voltage. Thereafter, this changes in voltage stabilizes to a higher voltage level on the amount of 111 percent of the working voltage (Long et al. 2013).

2. **Harmonics at DC MG**

In a DC MG, low-level harmonics are inactive since the absence of AC–DC converter, but expanded usage of the DC–DC converter will reason for the presence of electromagnetic interference. However, several times a DC device lacks harmonics, the term harmonics refers to different frequencies of the fundamental; it is known as operating frequency of a DC–DC converter. Harmonics in a DC circuit refer to fluctuating current and voltage began by the device's working frequency. Various converters operated by PWM pulse can be used in DC MG systems in various loads and generating stations, with capacitors attached on both sides of the converter. Different resonance frequencies are caused by resistance of the DC bus and the reactive impedances of different capacitors. Whether the particular frequencies are matching with the resonant frequencies, the influence of these harmonics on the DC MG may be disastrous (Railing et al. 2004).

3. **Inrush Current**

In an AC configuration, inrush current is caused by transformers, induction motors and other strong inductive loads; however, the explanation for inrush current in a DC MG is different. Harmonics are generated when multiple loads, dispersed generating stations and different storage devices are linked via power electronics converters. As a result, sufficient filter is mounted on the load side. Additionally, Electromagnetic Interference (EMI) filters are installed on the AC edge. In a DC MG, the capacitor in this EMI filter draws a lot of inrush current. The extent of inrush current is determined by the DC system's voltage frequency, capacitor impedance and converter capacitance. Another explanation for arrival current in DC MGs are that when it is not energized loads are switched it in a loop, their big filter capacitors draw a lot of arrival current. The arrival current is so large that it could result in actual welding at the point of contact (Akagi 1994).

4. **Fault Current**

In a DC MG, fault current is generated by capacitors added to the grid by converters or various distributed generating stations, or by the EMI capacitor filter. The total liability of current is limited by the converters' ratings meanwhile entire converters in power electronic are operated in closed loop. When only a small amount of faulty current runs from a DC MG due to a transformer used in Power Electronics, safety systems have a hard time distinguishing between overload and fault conditions. As a result, designing a proper DC MG security scheme is a significant challenge. Unlike an AC system, a DC circuit wouldn't be a normal voltage and current which are crossing the zero. This means that if an arc failure happens in a DC system, it wouldn't reduce as easily as it has in an AC system. Since it is a self-supporting liability and this is does not have surge current in the DC grid, it can persist for a lengthier duration and create a significant issue in the scheme. Lower fault current, otherwise, will exacerbate voltage unbalance in a DC MG when a fault occurs (Khadkikar and Chandra 2008).

This chapter is organized into the following sections: Section 17.1 illustrates the PQ issues and challenges in SG. Section 17.2 explains the various techniques and devices used for improving the PQ in SG. Section 17.3 discusses the PQ issues and challenges and their mitigation techniques related to DC and AC MGs.

17.2 Causes and Mitigation of Power Quality Issues in Smart Grids

In this chapter, the major causes of the PQ issues and their mitigation in SGs are explained in detail.

17.2.1 Harmonic Emission by Power Electronic Equipment

In the field of power electronics, there have been several recent advancements which have resulted in a greater integration of power electronic devices into existing electrical grids. On the one side, these devices improve grid stability and performance while also posing new problems, such as introducing harmonic content into the grid (Naderi et al. 2019). The majority of nonlinear loads such as power electronics gadgets, switcher, information handling apparatus and high-performance lighting loads are the major reason which cases harmonic distortion. Harmonic distortion is the one in which the waveforms of voltage or current take on a non-sinusoidal structure. The waveform is defined by a set of sine waves of various magnitudes and phases with frequencies which are multiples of the grid frequency. This in turn creates a major consequence in the grid such as upsurge in the occurrence of resonance, imbalance at neutral point in three-phase systems, overheating of wires as well as equipment, deterioration of electrical machine's output, interfering with electromagnetic waves in case of communication systems, measurement inaccuracy when using DC metres and spurious thermal safety tripping (Gandoman et al. 2018).

To reduce the effect of harmonics in the SG, filters can be used. Filters are broadly categorized into active and passive filters. Passive filters are the one which uses the combination of any one of the passive components like resistors, inductors and capacitors. Active filters combine both passive and active components and uses external source for its operation (Jolhe et al. 2016). The usage of a shunt active filter mitigates current-related PQ problems alike harmonic distortion, poor power factor and consumption of reactive power. Shunt active filters are connected between the power source and the load at the Point of Common Coupling (PCC). The active filter is typically made up of power inverters and functions as a balanced source of current (Senthilkumar et al. 2015). Figure 17.3 shows the SG with shunt active filter.

17.2.2 Interference Between Grid Connected Devices and Power Line Communication

Power Line Communication (PLC) is the first networking technology that came out with SG, and it now offers high-speed connectivity to a variety of SG applications. Narrowband transmission, spread-spectrum transmission and DSP-processed

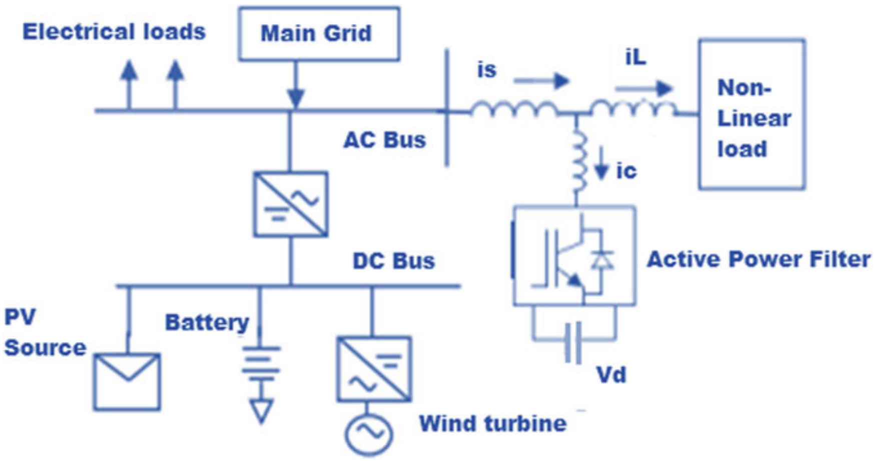


Fig. 17.3 Smart grid with shunt active filter

narrowband transmission are the three networking systems used in PLC. It seems that the spread-spectrum technology is quite disadvantageous since it diminishes the performance of PLC, when its channel is defective. On the other hand, due to the presence of the impulse noise, narrowband transmission system's performance also decreases. By integrating narrowband transmission and DSP, the results of impulse noise on narrowband transmission has been minimized and error-free communication is accomplished. DSP can also be used to resolve the narrowband transmission channel distortion issue, making PLC quite powerful. Commonly, power line communication (PLC) systems use the 1–30 MHz range to communicate a modified carrier signal over a prevailing grid. PLC employs symmetric connections which can transmit data at up to 200 Mbps. It has a range of maximum communication distances. It has a medium voltage of 3 km and a low voltage of 200 m. Until now, the greatest disadvantage of PLC has been the lack of regularity (Yigit et al. 2014).

PLC is used in many of the applications involved in SG. Some of the main applications are discussed below.

17.2.2.1 Infrastructure for Advanced Metering and Modern Monitoring Devices

PLC's two-way communication allows consumer devices and systems to communicate with one another in advanced metering infrastructure. Real-time pricing can be offered in this way by allowing service providers to communicate with metering devices. Customers will also read about their new billings. Because of its low maintenance costs, smart metering is cost-effective for utilities. Remote metre reading is accomplished using Ultra Narrowband PLC (UNB-PLC) technology. Despite the fact that UNB-PLC devices have a poor transmission rate, their connectivity range is 150 kms. PLC measures energy demand based on various time regions, for instance weekends and work hours. Further, it allows the identification of power theft as well as information gathering from another meter reading arrangements like water/gas metres. PLC's two-way data transmission often enables gas/water supply to be switched off on request once the customer is not in need of them for an extended period of time (Yigit et al. 2014).

A key parameter for understanding and optimizing system operation is monitoring in actual time and display of devices and output over a large region. Sophisticated system knowledge prevents brownouts and produces system logs in order to anticipate and prevent possible failures, produce for further decision-making, eliminate broad range disruptions and increase transmitting capacity and quality of the grid. This particular attribute marks the start of the trail that leads to PQ issues. SGs would be simply grids without these advanced metering and monitoring interfaces but activating this function will increase the performance, speed and precision of PQ issues in SGs (Naderi et al. 2019).

17.2.2.2 PLC-Based Electric Vehicle-to-Grid Connectivity

Integration of battery-operated PHEVs are made possible with the recent advancement in SG technologies. The battery of PHEV is energized by using electric vehicle supply equipment. The PHEV will communicate securely with the electric vehicle supply equipment using a PLC. The Society of Automotive Engineers has tested various PLC technologies like broadband-PLC and narrowband-PLC). In terms of applicability, narrowband-PLC has performed better (Yigit et al. 2014).

Figure 17.4 illustrates the infrastructure of the electric vehicles being charged from

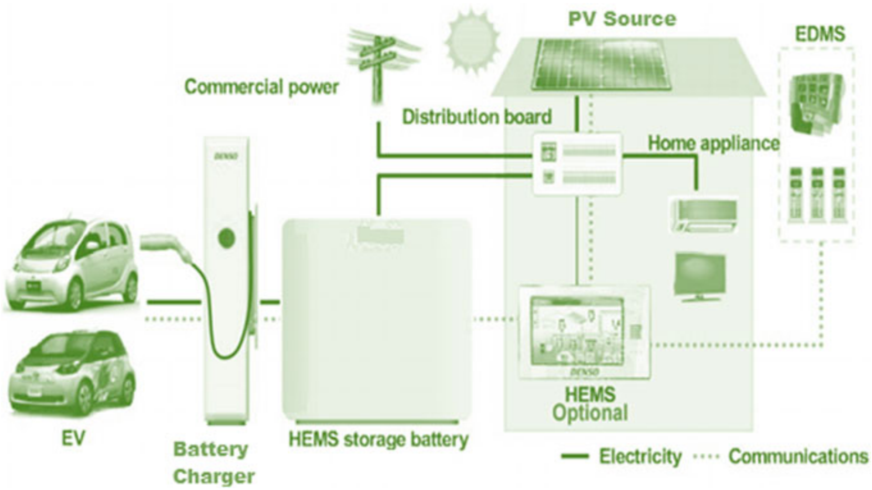


Fig. 17.4 Electric vehicle charging infrastructure (from grid to the vehicle)

the grid. As a result of the growing movement towards electric vehicles, the upcoming of the electrical grid would face a PQ issues. The incorporation of a significant number of storing elements that utilize rectifiers to energize batteries at various charging times would yield a significant consequence on the electricity grid's PQ. In addition, when adding various levels of harmonic into the electrical grid, peak demand would increase dramatically. If, on the other hand, these storage elements could be present as an appropriate demand-side management (DSM) resource, this task will be an initiative to strengthen the electrical system's reliability. This necessitates the passage of regulations governing the possession and use of electric vehicle storage devices.

17.2.2.3 Demand Response System

Demand Response (DR) responds to a variety of energy requests. DR uses a real-time pricing scheme to manage power conditions and improve device performance. Furthermore, DR can minimize peak demand and consumers have control over their energy consumption by means of a PLC between the electrical services and their home usages. A DR framework is implemented using a broadband-PLC and oblique control via a gateway. The Domestic/Building Energy Management System (HEMS/BEMS) is one of these indirect load applications. For the DR method, a less expensive solution, such as the narrowband-PLC, may be used instead of the BB-PLC (Yigit et al. 2014).

In brief, DR strategies that allow for efficient supply of electricity as well as demand management are believed to be a key component of the SG. Modelling consumer behaviour is one of the most difficult aspects of developing demand-side management models. Modelling customer relationship, constructing decision-theoretic methods, refining pricing, integrating complexities varying over time (e.g. demand fluctuations) and balancing for grid electricity restraints are altogether obstacles that must be addressed before implementing DR models.

Decision-theoretic strategies like game theory, optimization and stochastic control are needed for accurately modelling and analysing various arising DR conditions. DR is supposed to be a critical turning factor for SG implementations that are more realistic (Bari et al. 2014).

Apart from the above applications, PLCs are also used for in-home environmental applications, remote fault identification, mobile networks communication, in order to achieve peak demand elimination, reliability enhancement, diagnosing isolated fault in cables, identifying damaged insulators and to deliver greater bandwidth for voice and data communication. Though PLC's offer several benefits like, extensive coverage, cost-effective, higher flexibility, easy installation, highly stable and mobile, their disadvantages outnumber the benefits.

The major issues include the following: (i) Sources of high noise on power lines, (ii) The issue of open circuits, (iii) The signal is ameliorated and fragmented, (iv) Regulations for broadband-PLC are insufficient and (v) Compatibility is a problem (Yigit et al. 2014). Figure 17.5 illustrates the communication network for the SG.

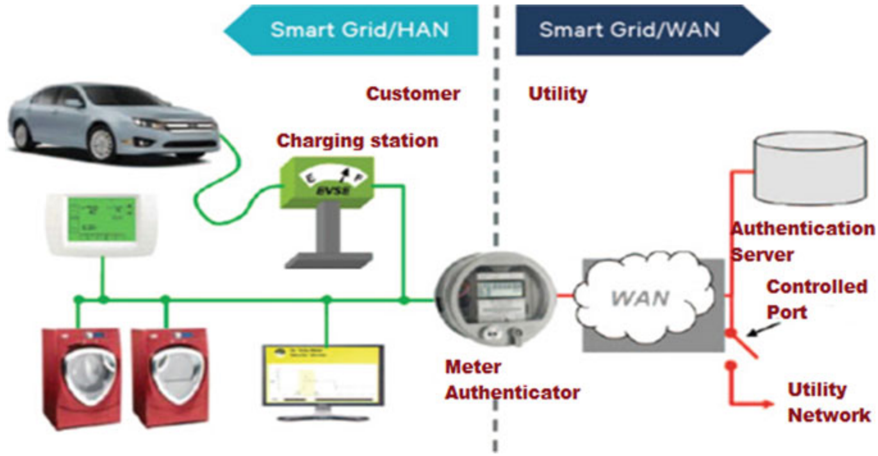


Fig. 17.5 Arrangement of communication network in a smart grid

17.2.2.4 Allotment of Restrictions of Emission on Grid by Integrating New Devices

When a new customer is tied to the controlled modern electrical grid, an estimate of the amount of pollution that is permissible from this customer without causing unreasonable amounts of voltage disruption for other customers is usually made. A so-called emission threshold is assigned to each new customer. Both current and potential customers share the cumulative amount of permissible voltage distortion. However, this means that the number of customers who will be linked in the future is understood. With modernization of the electrical grids, the quantity of demand would consume no limit as long as output grows at a similar rate. Because of the continued increase in both output and consumption, the voltage distortion due to harmonics may develop in to unusually larger threat. In addition, the number of times the switches need to be turned on and off will continue to rise, potentially reaching excessively high levels.

At the power system frequency, output and consumption are in equilibrium, but it's not the case with harmonic frequencies. Another way to look at it is that the system's intensity is now measured by the quantity of harmonic distortion being emitted by downstream apparatus, rather than the higher quantity of utilization and/or output related downstream. This will necessitate a new approach to distribution network planning. However, preliminary research has found that harmonic emission from distributed generation is very small. The majority of current end-user devices, such as computers, televisions and lamps, emit only at the lower odd integer harmonics (Bollen 2010; Pandya and Bhavsar 2018).

Immunity of Devices

An instantaneous tripping of several distributed generators can occur owing to a voltage quality disruption, or it can be said that it's because of a dip in voltage level. And this is a significant problem. Mass consumption tripping can have similar negative effects to how a SG seeks to keep a balance among generation and consumption (Bollen 2010).

Transmission Grid Deterioration

The volume of traditional generation interconnected with the transmission structure would decrease as distributed generation and huge wind parks become more common. As a result, the level of failure will be decreased, and power-quality disruptions will spread out further more. Voltage sags, rapid voltage variations (flickering in voltage) and harmonic variations would all be exacerbated. The magnitude of voltage dips has been investigated. The research concluded that even though 20% wind energy is harvested, substantial rise in the amount of voltage sags due to transmission system faults is not evident (Bollen 2010).

17.2.3 Integration of Renewable Energy Sources

The form of power generation has shifted from bulk generation units to distributed generation units as a result of sustainable energy sources like solar, wind, etc. As a result, the system's reliability, output voltage, electrical transmission expenses, damages and reliance on the primary grid have indeed strengthened. In spite of the above-said advantages, due to the stochastic aspect of sustainable energy sources such as solar or wind power, they are not completely efficient. Another disadvantage of incorporation of such sources in the grid is that they use high-power converters to transform power; as previously stated, excessive use of power electronic converters in the electricity grid would result in a lot of harmonic emissions. Recently, researchers have been working on ideas to generate these renewable energy sources infinitely customizable so that the grid's PQ would become better by the integrated power electronic converters. (Hosseini et al. 2017; Naderi et al. 2018).

17.2.4 Devices for Improving Power Quality in Smart Grid

This is important to enhance the efficiency of power supply on the customer side by using PQ control technologies and equipment. Controlling and converting electric energy to meet out the requirements of quality compliance and optimum performance is the significant aspect of PQ control. Various types of high power converters and

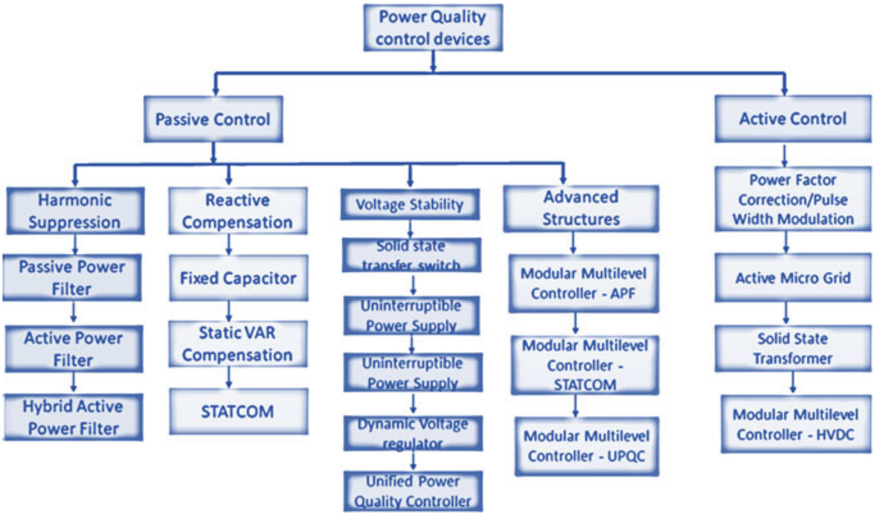


Fig. 17.6 Classification of power quality control

corresponding control topologies are key elements in achieving the above-mentioned control and conversion. Figure 17.6 depicts the category of compensators based on various types of PQ issues. There are two broad techniques available for the mitigation of PQ issues, viz. active control and passive control techniques.

17.2.4.1 Passive Components

Passive technique is described by incorporating various components to reduce or mitigate the effect of prevailing PQ issues. Currently, the passive power filter (PPF), active power filter (APF) and hybrid active power filter (HAPF) are the most common harmonic suppression strategies. Apart from their disadvantages, passive filter is implemented in certain particular applications these days due to their flexibility and a reasonable price. Its value noticing that the majority of those are applications of hybrid that use passive filters for cost cutting and improve overall device efficiency. APFs are designed to balance out and enhance power factor, mitigate harmonic distortion, balance malfunctioning and flickering of voltages and control voltage towards overcome the disadvantages of PPFs. APFs are of two types viz shunt and series APFs.

Shunt type of filters are connected in parallel for providing compensation for current harmonics through applying a harmonic current of the equal phase difference of 180 degrees and amplitude, resulting in nearly sinusoidal grid current. If an appropriate control system is used, it would act as a reactive power compensator. Harmonic voltages are compensated by incorporating harmonic voltages of the equal magnitude but opposite phase when harmonic loads are connected with series filters.

The key disadvantage of these devices is that they will have the same power rating as the load, making them a costly and unaffordable solution for high-power applications. Hybrid power filters, which combine the benefits of active and passive filters, are an appropriate option for lowering the price of utilizing high-rated active filters. In a high-voltage distribution network, it has proven to be an efficient method for mitigation of harmonic currents as well compensating the reactive power. Figure 17.7 illustrates the PPF, APF and HAPF.

The voltage disruptions and fluctuations are suppressed by the reactive power compensator, static VAR compensator (SVC), static synchronous compensator (STATCOM) and Fixed capacitors (FC) are examples of VAR compensators used in distribution networks (An et al. 2016). The STATCOM is one of these devices that is commonly used because of its various features, including grid voltage oscillation reduction and nonlinear load compensation. Due to its higher durability, consistency and specific power, extensible harmonic repression and VAR compensation systems are becoming successful. Figure 17.8 shows the devices for reactive power compensation.

Overvoltage and short disruption are the most frequently occurring types of intermittent PQ issues. The solid-state transfer switch (SSTS) will significantly minimize voltage sag complexity and length. The most powerful method for limiting voltage instability for low-power appliances in the distribution network is an uninterruptible power supply (UPS). The dynamic voltage regulator (DVR) will compensate

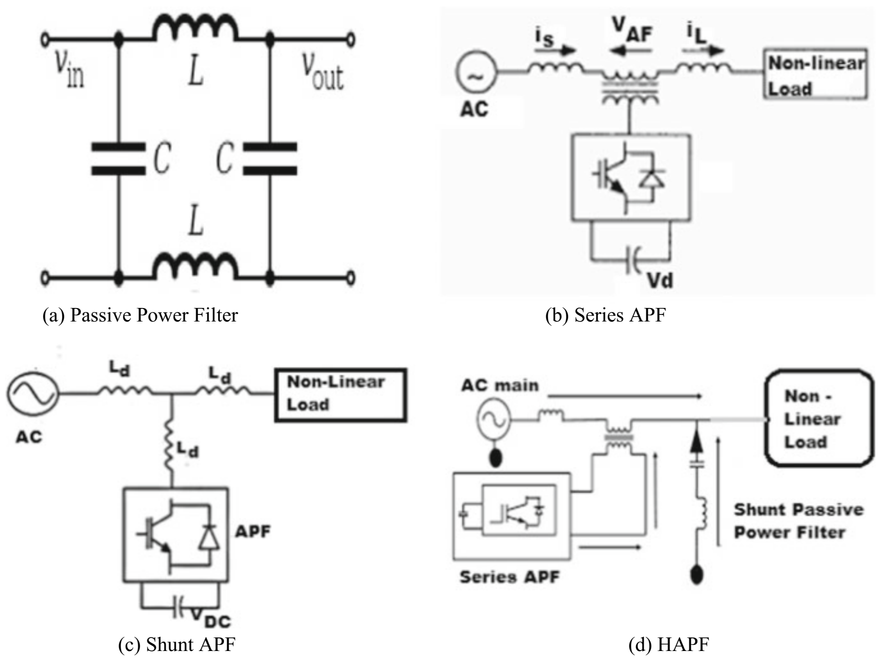
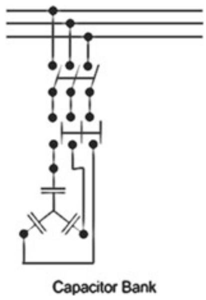
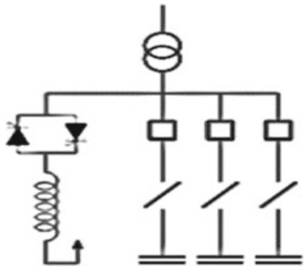


Fig. 17.7 Circuit diagram for PPF, APF and HPF

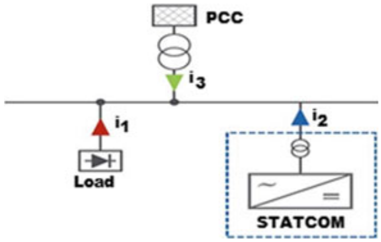
Fig. 17.8 Devices for reactive power compensation



(e) FC



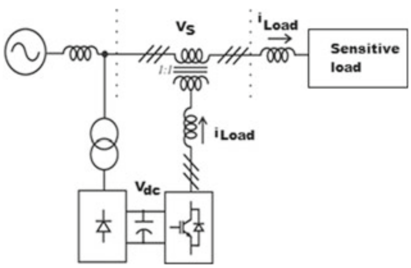
(f) SVC



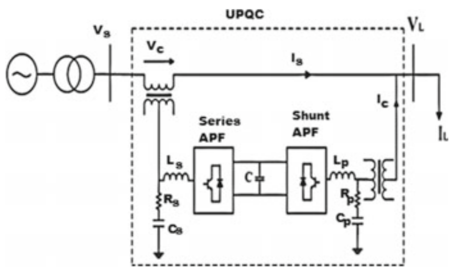
(g) STATCOM

for sudden voltage dip and swell directly and rapidly. The unified power quality controller (UPQC), which is made up of series and shunt APFs, will make comprehensive voltage and current compensation for the modern electrical grid. Figure 17.9 shows the elementary structure of DVR and UPQC.

Cascaded power converters based on modular multilevel converters (MMC) are extensively analysed in technical research and development applications in less than two decades. Modular multilevel converters significantly reduces the complexity and expense of producing high- and medium-voltage converters due to the similar module layout. MMC-based compensators have distinct advantages over conventional PQ



(i) DVR



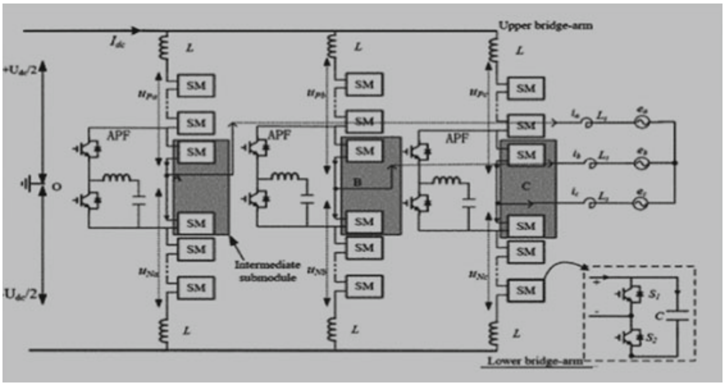
(ii) UPQC

Fig. 17.9 Elementary structure of DVR and UPQC compensators in terms of normalization, adaptability, flexibility, malfunction ride-through, load demand and filtering characteristics. MMC significantly reduces the complexity and expense of producing high- and medium-voltage converters due to the similar module layout. MMC-based compensators have distinct advantages over conventional PQ compensators in terms of normalization, adaptability, flexibility, malfunction ride-through, load demand and filtering characteristics.

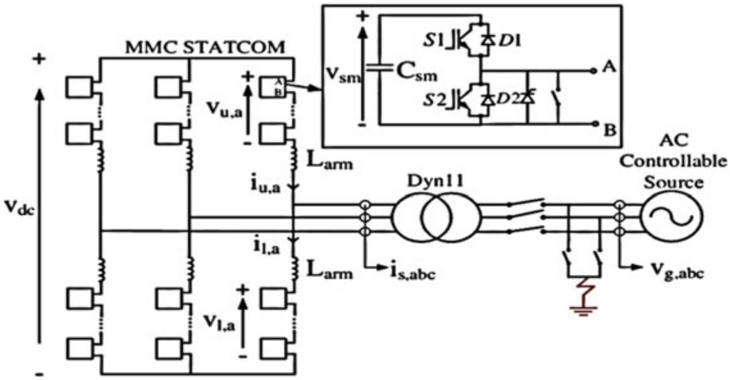
The versatile PQ control scheme will reduce the rated voltage of the semiconductor switches used in power converters and the unit for storing energy in the sub-system, allowing reduced losses and low-cost switching devices to be used. The cascaded framework, on the other hand, extends the use of sustainable PQ control scheme in medium- and high-voltage power transmission. Since huge amounts of data must be interpreted in a limited period of time, the multilevel structure necessitates a comprehensive control system. As a result, MMC's engineering application and advancement in the control of PQ issues is minimal. Thankfully, as digital signal processing technology advances, the implementation of complicated topologies and closed loop control are increasingly simple (Lesnicar and Marquardt 2003; Kouro et al. 2010; Ghetti et al. 2012; Long et al. 2013). Figure 17.10 describes the schematic diagram for modular multilevel converters based on APF, STATCOM and UPQC respectively.

17.2.4.2 Active Components

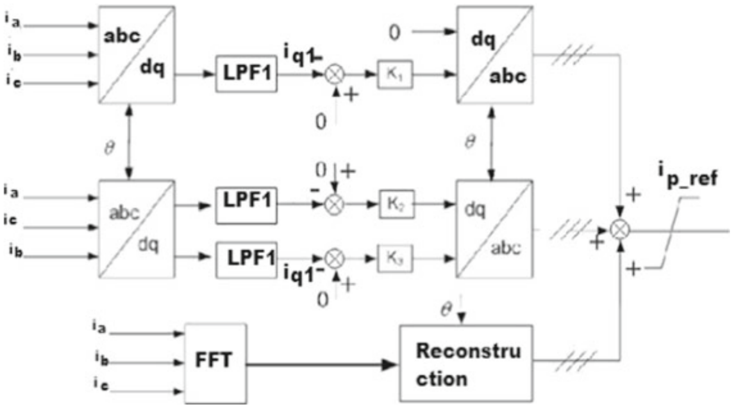
Most PQ issues are resolved by using active control technology to boost the intrinsic properties of electrical equipment. By means of transmission and distribution network being engineered, automated and smart, PQ issues posed through emerging electrical systems, particularly the high-power converters, would be greatly alleviated. The PQ of rectifier devices has been improved by power factor correction (PFC) techniques and pulse width modulation (PWM) methods. With the use of active control in distributed generation and MG inverters enhances the accuracy of voltage at the output and current in distributed systems, and at the same time offers additional compensation capability for the adjoining electrical grid. Consequently, the proposed solid-state transformer (SST) would prevent PQ problems from being transmitted and emitted in between end-user and the power delivery system. The MMC-type high-voltage direct current (HVDC) transmission and multi-terminal high-voltage DC technology would enhance the PQ of the entire power grid (Leung et al. 2010; Railing et al. 2004; Long et al. 2013; Akagi 1994; Khadkikar and Chandra 2008; Luo et al. 2009). Figures 17.11 and 17.12 show SST and MMC based on HVDC technology, respectively.



(i) MMC based on APF



(ii) MMC based on STATCOM



(iii) MMF based on UPQC

Fig. 17.10 APF, STATCOM and UPQC

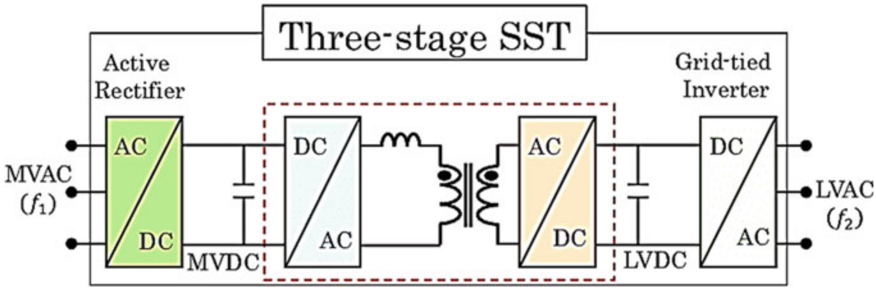


Fig. 17.11 Solid-state transformer

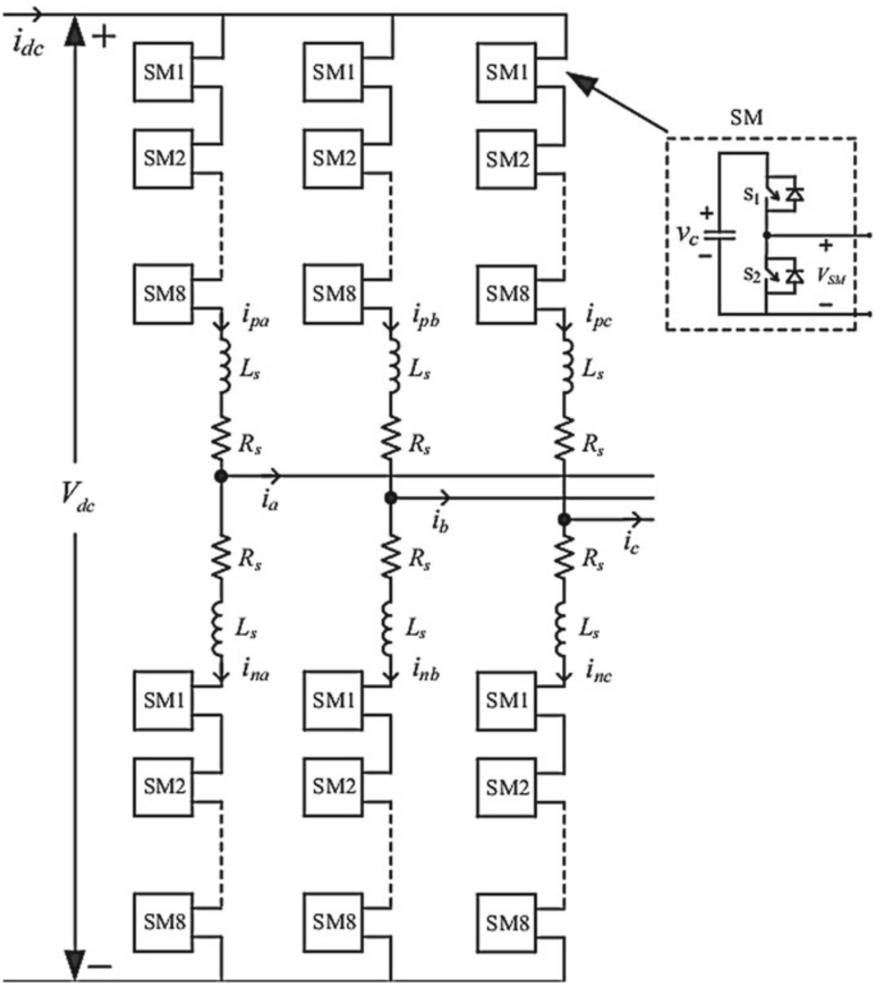


Fig. 17.12 MMC-based HVDC system Block diagram

17.3 Causes and Mitigation of Power Quality Issues in DC Microgrid

In this chapter, the major causes of the PQ issues and their mitigation in DC MGs are explained in detail.

17.3.1 Power Quality Improvement Methods for DC Microgrid

The control voltage of the DC bus is of prime importance intended for the typical function of the DC MG. To transmit effective power as well as current into the DC MG, the DC bus voltage must be controlled in a specific dimension by certain effective current-sharing techniques. Out of several techniques reported on the literature, the following are the most important and the effective one which are discussed as under:

(i) Voltage droop control method,
(ii) Hierarchical control method,
(iii) Multi-agent-based control method, and
(iv) Artificial Intelligence-based control method,
(v) Energy management strategy.

17.3.2 Voltage Droop Control Method

Droop control is a dynamic tool for improving PQ attributes like real and reactive power regulation in electrical grid as well as decentralized operations. The majority of today's current sharing approaches depend on a high-bandwidth infrastructure. As this DC MG is made up of multiple resources, implementing a high-bandwidth transmission network is not cost-effective. Figure 17.13 shows the droop control scheme. It is in turn a decentralized control scheme and it is more popularly used to enhance the MG performances. The traditional approach in this technique is to reduce the DC output voltage linearly as the output current rises. Current distribution among multiple converter topologies could be accomplished through the use of a configurable voltage variations that is confined within an appropriate range. By using high droop factor, the accuracy in current sharing can usually be improved. As a result, a larger droop factor is usually selected while limiting DC voltage variation at even the most drastic loading. This method of control is generally implemented for high-power converters, viz. DC to DC, DC to AC and AC to DC.

If V_r is the reference voltage, Io is the output current and r_d is the droop factor for the converter, the following two equations define the principle of voltage droop control method:

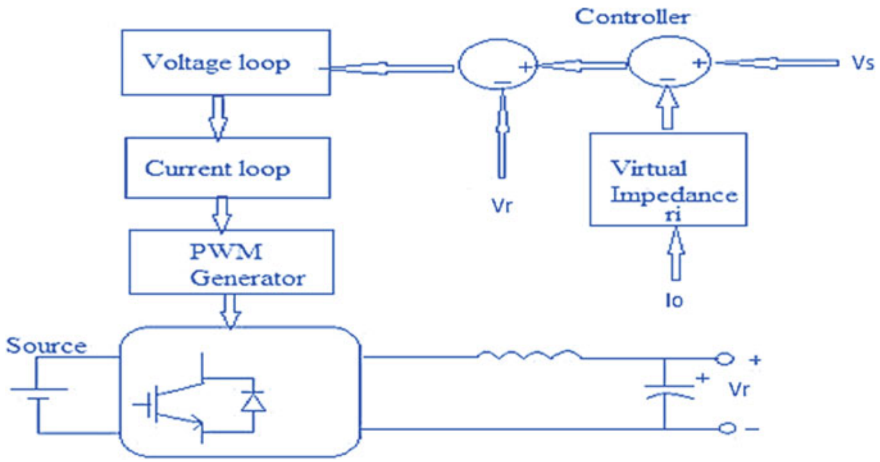


Fig. 17.13 Schematic diagram for a voltage droop control method

$$V_r = V_{r1} - r_d I_o \tag{17.1}$$

$$\Delta V_s = |V_{r1} - V_s| \le \Delta V_{smax} \tag{17.2}$$

Here, V_{r1} is the reference voltage, ΔV_s is the deviance in the DC MG voltage and ΔV_{smax} is the largest possible grid voltage deviance. In a droop-controlled DC MG, the droop factor rd is also known as virtual resistance. The major advantages of this method is that it is solely based on locally observed data and therefore does not rely on communications signal, thereby removing the challenges posed by specific location. Other benefits of the droop method include its simplicity, high efficiency, basic structure, ease of execution, unrestricted placing and multiple power ratings. Figure 17.13 illustrates the droop control implemented for a DC–DC converter (Rawat and Sathans 2018).

17.3.3 Hierarchical Control Method

Nowadays, control hierarchy is gaining popularity, because of their simplistic structure and high performance. In a nutshell, a DC MG faces complex converter-level control at the lower level but simple system-level organization at the top. Hierarchical control method plays a vital role to solve these features. In general, it comprises three control levels like, primary, secondary and tertiary levels of control strategies. Figure 17.14 shows the hierarchy control for the DC MG.

The primary control deals with the regulation of current, potential and voltage. It conducts control activities over interface control converters, following the collection

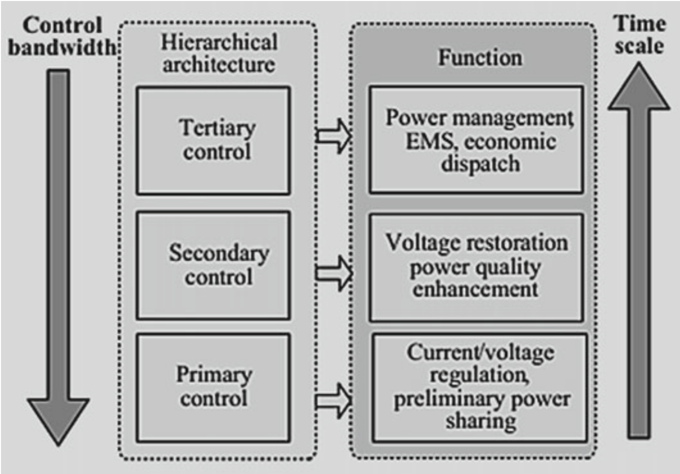


Fig. 17.14 Structure of hierarchical control

of focuses provided by upper level controllers. This primary control also focuses on the load sharing among the distributed generation units. The second level of control deals with system-level issues including control quality path, MG synchronization with the outside network for seamless reconnection and so on. The system's electrical levels are kept within the necessary limits by this central controller.

The tertiary level is the distribution management solution that also regulates the flow of power in the network system. The power flow among the DC MG along with the upper level electrical grid is regulated by this tertiary level of control. It interacts with the operator of the distribution system. The power exchange scheduling with the MG can be decided either by the distribution or transmission system's operator. The main goal of power management in DC MG is to keep the power balance between sources of energy, storage systems and loads as represented by the DC bus voltage. In order to maximize efficiency this tertiary management control determines the mode of function of the DC MG. Power sharing with the upstream side of the grid is included in interconnected mode control. The important feature of this control method is that if the load power is insufficient, the DC MG would draw power from the upper grid whereas if the power produced by the MG is in excess of what is needed, it will be transferred to the upper grid.

Depending on how secondary control is applied, these management techniques can be categorized into three main categories: centralized, decentralized and hybrid. In centralized control scheme, to overcome the voltage deviation induced by the principal controllers and also to establish balance of power among the distributed generations and loads in DC MG, centralized controller is used. This method can provide optimum control, restores the voltage level and at the same time eliminates voltage deviation which necessitates the real-time communication. In decentralized scheme, the distributed generations are independently regulated through local real-time feedback mechanisms either with communication or without communication. In the first case, i.e. decentralized control with communication, although correspondence amongst the distributed generations is essential, the operating choices are taken in a decentralized manner, typically at the level of the distributed generation. That's where the centralized secondary regulation differs significantly. In the second case of decentralized control without communication, all the required operations in this group can be completed without the use of communications. The DC bus signalling system is the most commonly used system. This approach departs from the principle of precise power sharing on the bus with limited voltage deviations.

Since the device is supposed to be power electronics-dependent, high-voltage deviations from marginal value are allowed because the line and load architectures can be configured to ultimately improve within a wider prescribed DC voltage. The key benefit is that switching between different modes of operations and altering with various appropriate control methods for power converters can be accomplished without the use of extra network communication. Cost savings and greater performance are the two added advantages. The hybrid secondary control combines the benefits of both centralized and decentralized controls in order to obtain greater performance and higher reliability. Many literatures are being reported on this hybrid control where in the basic idea is that, the first stage is activated when the communication accessibility services fail and is based on the DC bus system method. On the other hand, under normal service, the second stage is enabled in which the communication channel provides complete observability over the DC MG comprising actual bus voltage, active power flow and converter operating mode (Rawat and Sathans 2018; Natesan et al. 2014; Papadimitriou et al. 2015).

17.3.4 Multi-agent Control Technique

A multi-agent scheme combines various agents to accomplish a common goal. It consists of both software and hardware units with merely local data and limited capabilities, but it has the greatest ability to work together to achieve a global goal. The first and foremost attribute of the agents is that it can be any one of the specific physical modules. The other characteristics include the following: (i) they can interact with their surroundings and communicate with one another, (ii) without a controller it's possible for the agents to take its own decision, (iii) able to achieve specific targets by using its tools (either software or hardware), expertise and provisions. With the support of fast communication systems, multi-agent systems can be used in high-power applications more effectively and feasibly. Multi-agent control technique is shown in Fig. 17.15.

Distributed problem-solving is a subcategory of multi-agent control system that can be easily implemented on MGs and power systems, in which all the entities can cooperate to reduce operating costs and improve customer satisfaction. The basic principle is that an agent can analyse and evaluate the surrounding physical

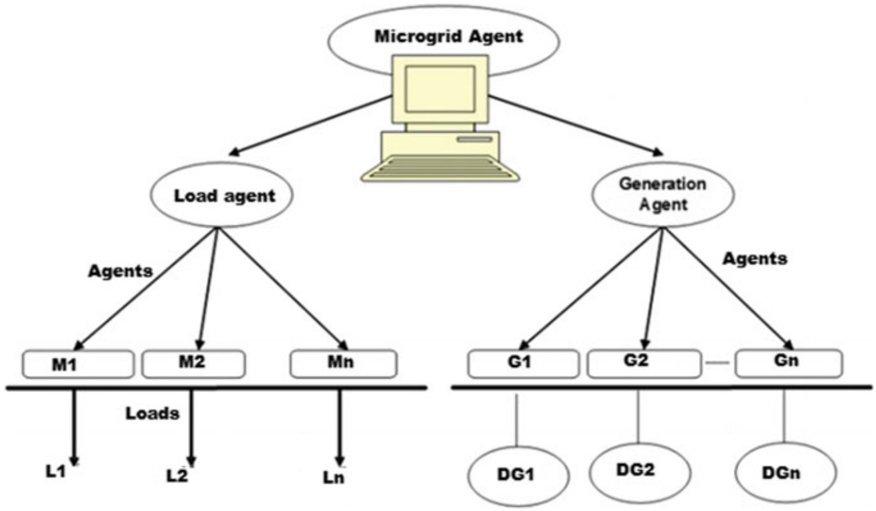


Fig. 17.15 Multi-agent control scheme

attributes, updates its local databases and responds to local events on its own. An agent can also work with other agents to coordinate and interact, negotiate offers and achieve both local and global goals. The method of designing a multi-agent system for MG power management is a step by step procedure which involves a thorough investigation of the entire power system.

First step is that complete technical details should be specifically outlined, including the comprehensive geometry of the MG, the number, form and priority of load, the total local supply generated by onsite renewable energy production and energy available in storage units and the highest possible demand that could be met in islanded mode. The specifications and goals are then defined, which are then converted into mathematical model and objective function for cost optimization. The total agents required, optimization techniques and performance metrics are then defined as per the above analyses. Finally, in both normal mode and islanded mode of operations, communications and information sharing among agents should be described. The end result is a complete model with specific behaviour of the agent which can be incorporated using a suitable agent framework like Java Agent Development Framework (Rawat and Sathans 2018).

17.3.5 Artificial Intelligence-Based Control Method

The traditional control strategy is insufficient for highly complicated or ambiguous systems. In such situations, artificial intelligence-based control has proven to be the best method for obtaining an effective control for the DC MG as well. Among many of the available methods, here we are going to discuss on the two efficient controls, viz., fuzzy logic-based control and PSO algorithm-based optimization control.

17.3.5.1 Fuzzy Logic-Based Control

The fuzzy controller was created with the help of human intelligence. It improves the capability to cope up with unpredictable or unclear data to some extent. Based on the literature, it is found that fuzzy logic controller is being used in DC and AC MGs, either stand-alone or grid-connected, for a variety of applications, including maximum power point monitoring of solar photovoltaic applications and wind energy systems, regulating battery output charge current and so on. The state of charge (SOC) of a Li-ion battery associated to a DC MG with fuel cells, photovoltaic system and wind energy systems was controlled with fuzzy logic controller. A decentralized control for gain scheduling using fuzzy logic controller was also reported in literatures to obtain balancing among the stored energy systems provided for various batteries by changing the droop coefficient of primary controllers in a DC MG. In order to supply a DC load, fuzzy logic control can be used to provide a power split between photovoltaic system and energy depository system of a battery based on the operator's expertise over a predefined set of fuzzy rules. In such cases, the controller takes three inputs such as from PV power, battery state of charge and load power. The controller's output controls the operation of the various switches, allowing for one of the three possible connections like PV power/battery, battery/load or PV power/load.

In general, when this fuzzy controller is used in MG, the control system is divided into two tiers, with control bandwidth separating them. The voltage and current controls for the DC/DC converters are located on the primary stage. The latter is configured to monitor the commanded reference values with quick disturbance rejection and a high bandwidth control loop (i.e. >500 rad/s). The fuzzy logic controller which is configured to have a lower bandwidth, represents the secondary stage. This is a general rule for nested control loops to maintain system stability. The controller regulates the flow of power in the MG as per the pre-determined regulations. Its output manipulates the primary control level's reference values (voltage or current) (Chilukuri 2021).

17.3.5.2 PSO Algorithm-Based Optimization Control

PSO (Particle Swam Optimization) algorithm can also be applied for enhancing the PQ in an individual DC MG and is being widely discussed in many literatures. This algorithm can be used to address voltage control, frequency control, sharing of power in the MG, stability, dynamic characteristic response or harmonic analysis among other PQ specifications. A real-time PSO algorithm-based self-tuning control technique can be implemented in a DC MG to enhance power efficiency. There are two feedback loops in this control technique. The first is a current mode control loop which is mainly based on a synchronous reference frames that acts as an inner control loop and the second is a power mode control loop associated with traditional Proportional–Integral (PI) controllers that serves as an outer control loop (Natesan et al. 2014).

17.3.6 Energy Management Strategy

The energy management strategy or more commonly energy management system (EMS) plays a critical role in maximizing the use of renewable energy sources to meet load requirements. Depending on the selected circumstances, an energy management system is needed to organize the energy sharing among these multiple sources connected with the MG an energy management system is a set of computer-assisted software used by electrical power system managers for monitoring, controlling and maximizing or optimizing the output of generation sources. Due to the introduction of renewable energy sources, this control strategy now plays a critical role in MGs. Higher number of power converters are employed in MG for power flow control operation. These power electronic-based high-power converters respond to grid variations in accordance with the proposed grid's energy management algorithm (Khatibzadeh et al. 2017).

The combination of energy management control system and power electronic converters simultaneously controls and manages the MG system. Photovoltaic arrays and hybrid energy storage system can be programmed to get the most power out of renewable power resources. Energy management control is commonly needed in hybrid energy storage system for deciding the number of storage units which is to be used in each cases, as well as the discharge cycles for each unit (Tazi 2019; Badwawi et al. 2016). The total power produced plus or minus the power supplied by the energy storage device should be equal to or greater than the total power consumed by the load. The control algorithm is defined by the following equation:

$$P_{gen}(t) \pm P_{enr}(t) \geq P_L \tag{17.3}$$

Here, $P_{gen}(t)$ is the instantaneous value of the generated power, $P_{enr}(t)$ is the instantaneous value of the power delivered by the energy storage system and P_L is the instantaneous value of load power.

The electrical system's energy control is critical for resolving issues in a hybrid energy storage system. The lifespan of each energy storage unit can be extended by monitoring the charge-release period. The energy management system's function here is to use the super capacitor to reduce the amount of discharge cycles of the battery during short-term load changes (Sayed and Kassem 2019).

17.4 Causes and Mitigation of Power Quality Issues in AC Microgrid

In this chapter, the major causes of the PQ issues and their mitigation in AC MGs are explained in detail.

A MG associates with the distribution network through control of AC bus. The AC bus controls the MG's assembly to and disconnect from the distribution network via the relay called circuit breaker at the Point of Common Coupling (PCC) is known as AC MG. In AC network, frequency and voltage are the dual quantities which are needed to be controlled. The frequency can be changed by changing the input mechanical power and the voltage is organized by injecting or fascinating the reactive power in AC generators (Guerrero et al. 2013).

The distribution scheme is associated to the AC bus via a circuit breaker in an AC MG, and the AC bus controls the MG's operating system via the circuit breaker at the PCC. In an AC MG, the PCC is basically a 3ϕ AC bus.

The MG control system must be capable to function reliably in two modes called grid-tied and islanded modes, with a smooth transition among them. In MGs, various control techniques like management of power, grid constraint management and PQ enhancement are carried out using multilevel controls called hierarchical control schemes (Karim Hassan Youssef 2019).

There are four different forms of MG control:

I. Output control of Converter,
II. Control for Power sharing,
III. MG supervisory (secondary) control, and
IV. The grid supervisory (tertiary) control.

Figure 17.16 depicts the various levels of power. The higher level controller provides each control level set points reached from data measurements, and contact with additional control levels (Pei et al. 2004), which are reviewed in this chapter.

17.4.1 Output Control of Converter

Voltage source inverters (VSIs) are made use in renewable energy power conditioning systems. Localized controllers monitor VSIs and their work is reached from limited measurements, which provides speedy reply than the mastery controllers in MG, and it could be capable to control in both grid-tied and islanded (standalone) modes. As a result, the system of control can be able to accommodate both modes. Figure 17.17 illustrates the formation of the converter output power.

There are two control loops in the present system. The inside loop current forms the current, while outer control loop controls the stream of active power and reactive power or controls the frequency and the output voltage of the converter depending on the modes of operation. The various types of current controllers are:

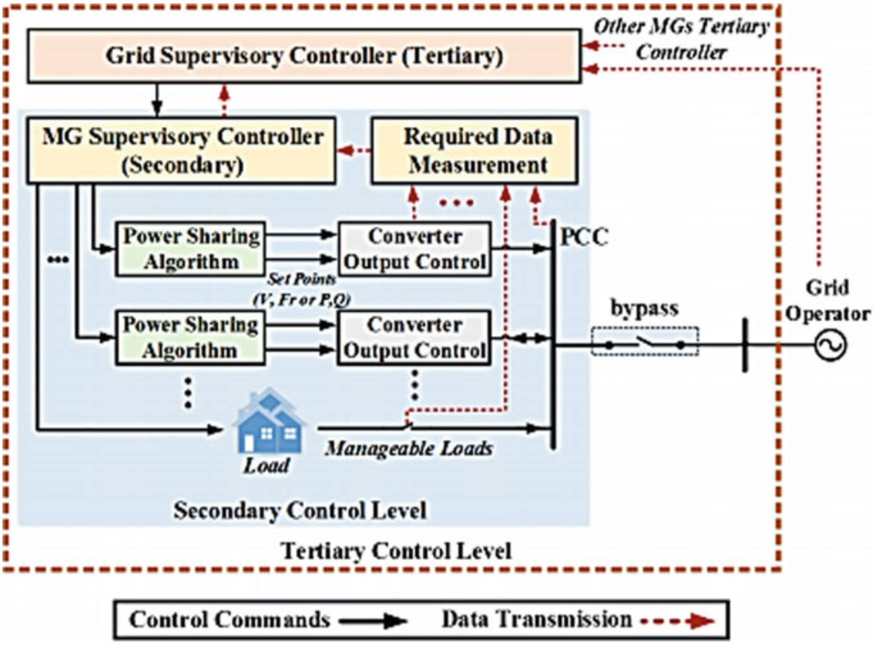


Fig. 17.16 Levels of control

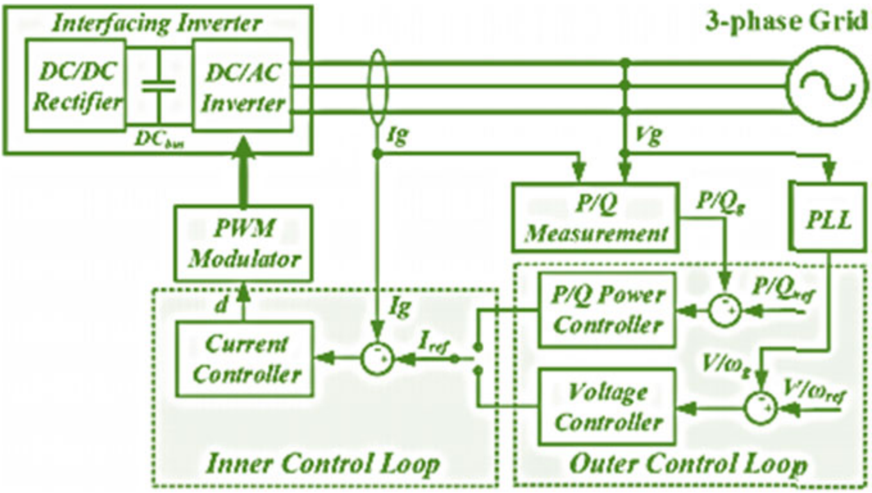


Fig. 17.17 Structure of Converter output control

(a) Conventional PI, PR and Hysteresis Band;
(b) Digital repetitive;
(c) Composite Nonlinear controller; and
(d) Composite nonlinear feedback control.

The functions of current controllers are expressed in Fig. 17.18, which shows a block diagram of various current controllers.

Integral controllers and Hysteresis band controllers are the most widely used controllers. The main advantage is that the steady state error and periodic distortion induced by periodic fluctuations are brought down. When the Overall Harmonic Disruption is low, the compensator based on Hysteresis band enhances the tracking

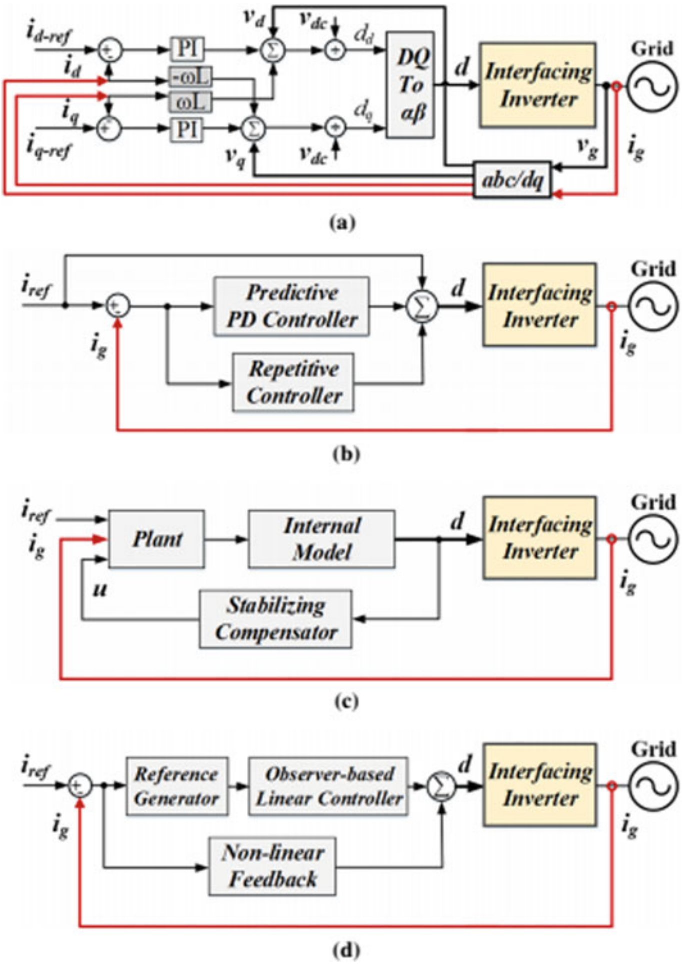


Fig. 17.18 Block diagram of various current control **a** PI controller **b** PR controller, **c** hysteresis band and **d** composite nonlinear feedback control

performance (Guerrero et al. Apr. 2013; Pei et al. 2004). The current loop's steady state and transient output are improved by the composite nonlinear feedback controller (Caldognetto and Paolo 2014).

In the Fig. 17.18, the inner current control loop can be initiated and the fix point for the inner loop is brought by the outer loop control. Hence the VSI output current VSI is controlled by using inner control loop (Guerrero et al. Jan. 2011). An external or outer current control is classified into two types which is depending upon the operating modes of power converter: They are: (1) Grid tied and (2) Stand-alone (Islanding) modes.

17.4.1.1 Mode of Operation Based on Grid Connection

Here, the primary focus is to regulate both active and reactive flow of power among the power converter and the motor/generator set. In order to regulate the active/reactive power flow, the converter has to work in the active mode, especially under current control mode to standardize the injection or absorption of the power, and a required active or reactive power is set as a reference point for the closed-loop system that must have been given by a system employed for monitoring and control (Guerrero et al. 2011). The converter will use these control schemes to execute the new synchronized control activities like effective control of voltage, power flow and unexpected failures.

17.4.1.2 Mode of Operation Based on Islanding Connection

Here, the MG is segregated from the main electrical grid and it controls both grid frequency and grid voltage. The new controller has a particular proportional-resonant control strategy along with the suppression of harmonics, which also includes a controller based on alpha–beta frame. Thus, the output control of converter is accountable to govern the transfer of output current and the power flow. With the help of this controller, the PQ issues of power of disparity is reduced.

17.4.2 Control for Power Sharing

In order to control the frequency and magnitude of the set point voltage, the control layer of the power-sharing should be added. Variation in frequency and voltage could be found from the upper control layer, and the control layer can be mentioned depending on the communication/without communication as shown in Fig. 17.19 (Pei et al. 2004).

In the Fig. 17.19, centralized current control, the controller gathers every information and at that time subject the instructions to the network. Though, this kind of method whose inverters function as source of current, and through the intermediate controller the voltage is measured. The master–slave controller is different to previous

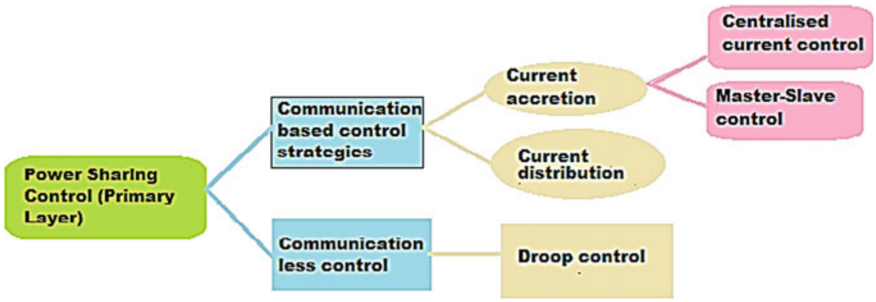


Fig. 17.19 Power control scheme organization

controller, in which ‘M’ no. of inverters have paralleled, among ‘M’ inverters, one inverter plays as a master whereas the remaining inverters plays as a role of slave. This type of controller transfers information among the master and slave. This type of controller has more economy, reliability and all information passed through common networks (Bhende and Kalam 2018).

In general, the balanced system can be controlled by distributed control system. The average current demand and the output voltage can be managed voltage controller. Droop control is the control; it has got extensive receipt since the nonappearance of the communication necessities among the inverters. The key knowledge is to control the frequency by sensing the reactive power and voltage by sensing the active power which could be sensed by the parameters.

17.4.2.1 Methods of Power Sharing in Island Mode

These are broadly classified depending on the connectivity channels as communication and as well as non-communication-based systems. These are further sub-divided in to different methods as follows:

(1) Communication-based methods
(a) System for sharing power centrally,
(b) Master–slave power sharing system,
(c) System for distributed power sharing.

Figure 17.20 depicts a block diagram for three types of contact connections. The central controller uses the high-band communications. Low-band contact is used in master–slave operation, where the master manages the voltage and the slave acts as a current controller (Dou and Liu 2013). It describes a smart master–slave communication system that enhances the transient response of the master–slave communication (Pearline and kamalini; Abinaya et al. 2019). A current sharing bus with low bandwidth communication and additional local controllers are included in the distributed sharing system to exchange information between the inverters (Alkahtani 2019).

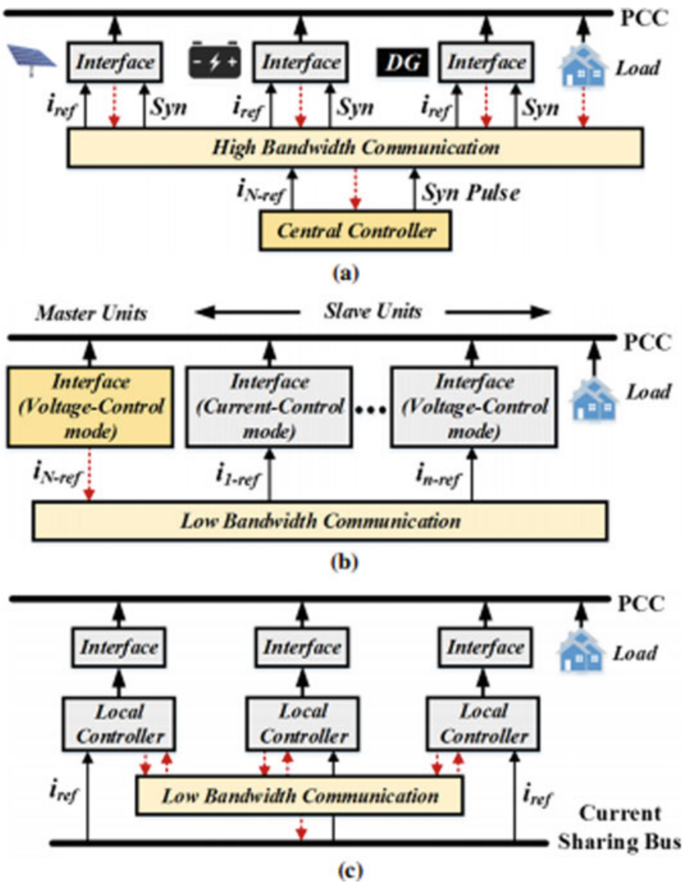


Fig. 17.20 Power sharing methods in Islanding mode. **a** central sharing, **b** master–slave and **c** distributed sharing

17.4.2.2 Non-communication-Based Method

This method uses no communication to enforce power sharing between parallel VSIs. The key benefit of this approach is its higher efficiency, lower costs and better scalability, which makes it a common choice in MGs. Droop-based control methods are also employed, i.e. P–ω droop/Q–V droop control is employed. The following are the key drawbacks of these controllers:

(1) The output impedance to resistance ratio has a high dependence on it.
(2) In data transmission, the PQ is poor.
(3) Voltage/frequency deviations.

Thus the control of power sharing is to control among the parallel inverters in which the control is responsible for the power flow among MG and utility grid. In the power sharing control, centralized current control can be obtained from the perfect current sharing even in the transient situation, no variation in the control organization and voltage regulation and various power rating of inverters could be connected with the structure. The master–slave operation control confirms the effective and consistent function of the MG in all operating condition. In the case of distributed control, which shares good current sharing even in the transient condition, minimize the circulating current and minimize the requirement of communication link. The method of droop consists of several required structures like stretch ability, compatibility, severance and flexibility. It has the advantages of very good reliability, efficient and various power-sharing and require low bandwidth (Failed 2019).

17.4.3 Secondary-Level Microgrid Supervisory

It handles the MG internal parameter guidelines to the MG and offers set points of low levels. The common control of the main grid could be attained through secondary-level control. On behalf of the inexpensive process, consistent and safe of main grid in two modes (Islanding and Grid-tied) secondary controller level or main grid Power Supervision Arrangement (PSA) is typically used. In islanding mode, the secondary control is the maximum hierarchical level in main grid with minimum bandwidth communication link and delayed control loops associated to primary control.

There are two types of controls for this. (1) Decentralized controllers using localized variables and (2) Centralized regulators relying on contact linkages to transmit data from the supervisory control to the controllers provided at the lower level.

17.4.3.1 Microgrid Supervisory Controller for Decentralized Structure

In this structure, the drawbacks in conventional droop control are overcome by augmented sags and by employing controller for compensating the distributed system.

17.4.3.2 Centralized Microgrid Supervisory Control

For collecting information and transmitting signals for controlling the power converter, these controllers depend on a high bandwidth communication networks and controller provided centrally. In the view of hierarchical management, such centralized control is implemented on the MG to ensure its reliability (Senthilkumar et al. 2015). The proposed hierarchical control structure has three levels of control: the primary level, which includes the controller for converter performance, optimizing algorithms for sharing power flow, the regulation on secondary level for maintaining the MG's potential as well as frequency, and finally tertiary level, which controls the flow of real and reactive power flow among the main electrical grid and MG.

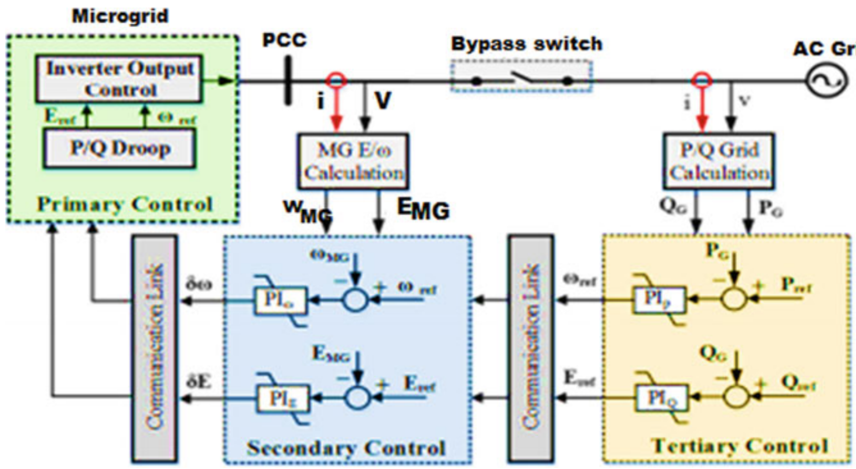


Fig. 17.21 AC hierarchical control system block diagram

The schematic diagram of the above-described hierarchical system is presented in Fig. 17.21.

In order to attain precise sharing of reactive power is an enhanced droop control scheme has been anticipated, which comprises multi-processes to progress the sharing of reactive power sharing through regularly changing the voltage bias of the simulated droop features curve and to bring back the graded rate of the output voltage. Lesser bandwidth communication links are enough for this kind of controllers.

17.4.4 Tertiary Level of Grid Supervisory Control

Tertiary level is the optimum level of control. This level acts as a current mode controller that uses communication networks for appropriately communicating with the operator available on the main grid and also with additional tertiary level controllers provided on the MGs so as to accomplish optimum reference for controllers at secondary level. This in turn comprises V/f control and real/reactive power flow control. Multi-gent scheme (MAS) is MGs' advanced control structure is developed to implement a conceptual framework depending on MAS which could manage stable potential in the meantime maximizing MG's activity at low cost. Figure 17.18 illustrates the diagram for the described control structure. It accomplishes the power flow among MG and the main grid.

From Fig. 17.22, it is seen that this control system comprises three different agents or levels of control: Unit agents or lower level agents which contains the controller of the power converter as well as sharing of power, the second agent called as the middle level coordinated agent comprises the central regulator of the MG and the third one known as the upper level agent accomplishes the collaborations among

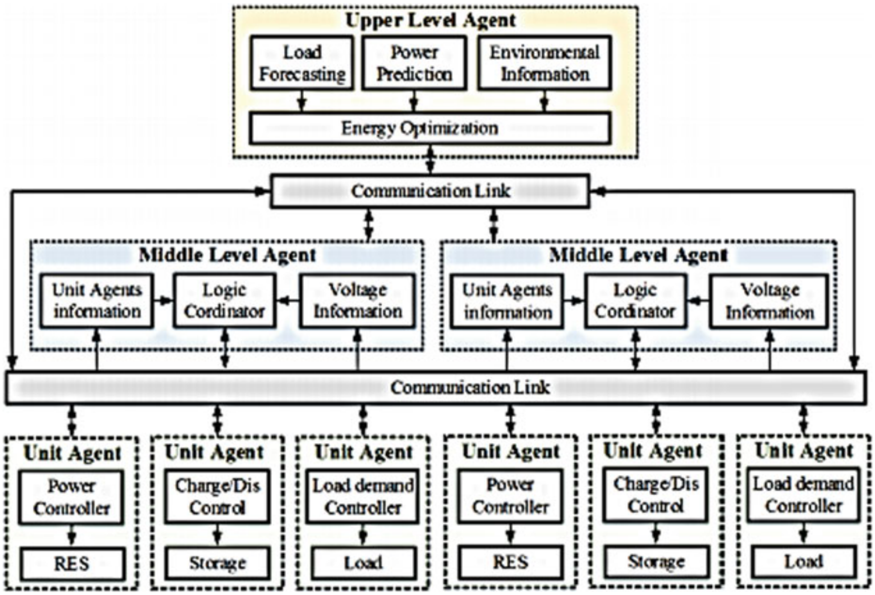


Fig. 17.22 MAS-based hierarchical control system

the main electrical grid and the MG (Dou and Liu 2013) proposed this MAS agent control level and this needs communication link to share the data among them.

The grid-tied tertiary control is used to control the magnitude and frequency of the voltage output. A tertiary level is slower and higher order of the control hierarchical, where the set points of the level of secondary are provided by this level. In grid supervisory control level, centralized control strategy is typically used. Therefore, the communication link is essential to retain the tertiary-level controllers in connect.

17.5 Conclusion

A detailed study of PQ issues and challenges in the SG and MG (both AC and DC) has been proposed. Initially, the structure of both SG and DC as well as AC MG has been explained. Various terms related to PQ issues are identified and their definitions are given in detail. In addition to the above a detailed explanation of each and every available PQ control, improvement tools and techniques are also discussed. More focus is emphasized on the various control techniques for enhancing the PQ has been given. It is to be noted that in SGs, two different technologies based on active and passive control have been discussed. Different types of filters like active, passive and hybrid power filters and other devices like Static VAR compensators, STATCOM, UPCQ, multilevel converter control, etc., are explicitly studied and their role in mitigating the voltage deviations, voltage sags, voltage swell, flicker, harmonic distortion, immunity of new devices in SG, transmission fluctuations, etc., are very well illustrated. Similarly, the DC MG control and AC MG control methods are deeply analysed. Extensive elucidation of various control techniques for improving power flow, power sharing, voltage balancing and regulation, voltage/ frequency deviation control, improved MG monitoring and control techniques, etc., are presented.

17.6 Future Scope

This work is proposed to be carried out by optimizing any one of the active devices to be implemented for mitigating the PQ issues in SG.

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