Chapter 2

Literature Review

Introduction

This chapter describes the fundamentals of reactive power and its requirement and necessity to compensate in MG. A literature review of RPC in MGs is presented based on various control techniques, algorithms, and devices utilized. It finally concludes on the CPD application for power quality improvement.

2.1 Reactive Power

Even a few years back, the main concern of electricity was the reliability of supply. Here the term reliability is defined as the continuity of electric supply. DG connected MG can solve this problem up to some extent. It is however not only reliability that the consumers require these days, but the quality is necessary. The firmly and tightly coupled MG generation is also facing a challenge in this direction. For example, a consumer that is connected to the same bus that supplies a large motor load may have a severe dip in the supply voltage every time the motor load is switched on. In some extreme cases, it may have to bear with the blackouts. This may be quite unacceptable to most consumers. There are very sensitive loads such as hospitals (life support, operation theater, patient database systems), processing plants (semiconductor, food, rayon, and fabrics) in case of industrial MGs, air traffic control, financial institutions and numerous other data processing and service providers that require clean and uninterrupted power. In several processes such as semiconductor manufacturing plant or food processing plants, a batch of product can be ruined by a voltage dip of very short duration. Such customers are very wary of such dips since each such interruption cost them a substantial amount of money. Even short dips are sufficient to cause contacts on motor drivers to drop out. Stoppage in a portion of the process can destroy the conditions for quality control of the product and require restarting of production. Thus in this scenario in which the customers increasingly demand quality of power, the term power quality attains increased significance. As mentioned in the chapter 1, most of the power quality issue arises in maintaining the voltage level at constant.

The steady state of the voltage, in turn, depends upon the compensation provided and vice versa. The reactive power compensation w.r.to voltage problem mitigation improves the system performance. Hence this chapter presents the basics of reactive power and compensation methods, RPC requirements in the MG, the study of various RPC techniques from the literature. The causes of the power quality problem are generally complex and difficult to detect. The ideal AC line supply by the utility system should be a pure sine wave of the fundamental frequency (50/60 Hz). In addition, the peak of the voltage should be of rated value. Unfortunately, the actual AC line supply that is received everyday departs from the ideal specifications.

The fundamental definition of reactive power can be explained by first looking at the relationship between a sinusoidal voltage and current waveforms of the same frequency. Reactive power has its origin in the phase shift between these two waveforms. When a device consumes real power such that the voltage and current waveforms are in phase with each other, the device consumes zero reactive power. When the current defined "into" a device lags the voltage, it consumes reactive power. The amount of reactive power consumed by the device depends on the phase shift between the voltage and current.

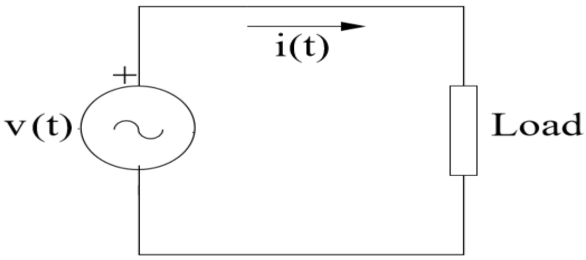

FIGURE 2.1: A single-phase circuit

2.1.1 Sinusoidal Excitation and Current - Review of Basic Conditions

A single phase circuit shown in Figure. 2.1 comprising a sinusoidal voltage source connected to a linear passive load. If the instantaneous voltage and current are given by

$$v(t) = \sqrt{2}\,V\,cos(\omega t) \tag{2.1}$$

$$i(t) = \sqrt{2}\,I\,cos(\omega t - \phi) \tag{2.2}$$

The sinusoidal nature of current depends on the nature of load connected and generally is sinusoidal in steady state. The relation between voltage and current phasors is:

$$\hat{V} = \hat{Z}\,\hat{I} \tag{2.3}$$

where $\hat{Z}$ represents the complex impedance and has a magnitude of Z and phase angle ϕ. The instantaneous power p, is given by

$$\begin{aligned} vi &= 2\,V\,I\,cos(\omega t)\,cos(\omega t - \phi) \\ &= V I\,[\,cos\,\phi + cos(2\omega t - \phi)\,] \end{aligned} \tag{2.4}$$

The average power P is defined as

$$P = \frac{1}{T}\int_0^T vi\,dt = V I\,cos\,\phi \tag{2.5}$$

The reactive power Q is defined as

$$Q = \sqrt{S^2 - P^2} \tag{2.6}$$

where S = V I is defined as apparent power. Substituting (2.5) in eq (2.6) we have

$$Q = \pm VI\, sin\, \phi \tag{2.7}$$

The sign is taken to be positive if $\hat{I}$ lags $\hat{V}$ by angle ϕ. The power factor (PF) is defined as

$$PF = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}} \tag{2.8}$$

From (2.8), the ideal PF of the system is always unity to which simultaneously the reactive power is to be compensated.

The apparent power S or complex power $\hat{S}$ is defined as

$$\hat{S} = P + jQ = \hat{V} . \hat{I}^* \tag{2.9}$$

Hence, reactive power Q is the imaginary part of the complex power. The power triangle is shown

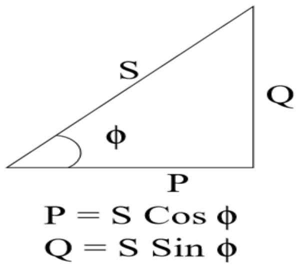

FIGURE 2.2: Power triangle

in Figure 2.2 which shows the relationship between P,Q and S. The P, Q and S are dimensionally same and the corresponding units are Watt, VAR and VA.

2.1.2 Reactive Power in Non-Sinusoidal Conditions

The definition of Q in a system is different when nonlinear loads are connected. This is due to the rise of nonsinusoidal voltages and currents even the source may be sinusoidal. On the other hand, nonsinusoidal currents, in turn, make the voltages nonsinusoidal. However, to simplify the analysis, it will be assumed the current harmonics result from voltage harmonics.

2.1.2.1 Definitions of Power in Time and Frequency Domain

It is worth noting that definition of active power in the time domain (2.5) applies even if v(t) and i(t) is non-sinusoidal. It is assumed that both v(t) and i(t) are periodic in steady state and have only AC components (no DC components). The active power P, is defined by

$$P = \frac{1}{T}\int_0^T vi\,dt \tag{2.10}$$

From Fourier analysis, both v(t) and i(t) can be expressed as

$$v(t) = \sum_{n=1}^{\infty} v_n = \sum_{n=1}^{\infty} \sqrt{2}\,V_n\,cos(n\omega t + \alpha_n) \tag{2.11}$$

$$i(t) = \sum_{n=1}^{\infty} i_n = \sum_{n=1}^{\infty} \sqrt{2}\,I_n\,cos(n\omega t + \beta_n) \tag{2.12}$$

Substituting Eqs (2.12) and (2.11) in (2.10), it is possible to express P as

$$P = \sum_{n=1}^{\infty} P_n \tag{2.13}$$

where

$$P_n = V_n I_n\,cos\phi_n \tag{2.14}$$

P_n is the harmonic power due to the harmonic v_n and i_n.

$$\phi_n = \alpha_n - \beta_n \tag{2.15}$$

The harmonic reactive power Q_n is defined as

$$Q_n = V_n I_n \, sin\phi_n \tag{2.16}$$

The apparent power S is given by,

$$S = V \, I \tag{2.17}$$

where

$$V^2 = \frac{1}{T} \int_0^T v^2 \, dt \tag{2.18}$$

$$I^2 = \frac{1}{T} \int_0^T i^2 \, dt \tag{2.19}$$

V and I are rms values of voltage and current respectively. Using Eqs. (2.11) and (2.12),

$$V^2 = \sum_{n=1}^{\infty} v_n^2 \, , \; I^2 = \sum_{n=1}^{\infty} i_n^2 \tag{2.20}$$

$$PF = \frac{P}{S} \tag{2.21}$$

2.2 Reactive Power Compensation in Single Phase Circuits

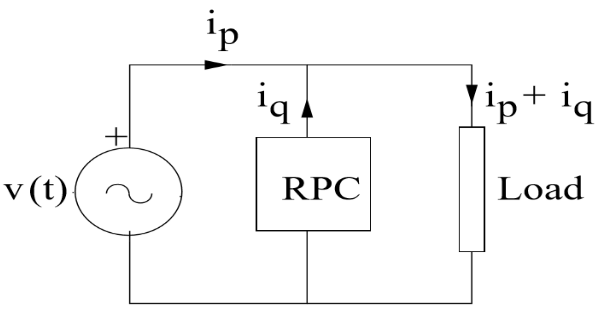

FIGURE 2.3: A RPC in a single phase circuit

I_p and I_q are the instantaneous active and reactive current. On the other hand, I_q the RMS value of i_q(t) is defined from Q_F = V I_q as:

$$I_q^2 = \frac{1}{T} \int_0^T i_q^2 \, dt \tag{2.22}$$

The Q_F gives the full compensation consisting only active current (i_p) delivered from the source as shown in Figure. 2.3). This gives reduced losses in the line and makes source power factor as unity. The RPC can be provided by an active filter or a combination of passive filter and active filter. The passive filters are traditional filters and have the drawbacks of bulky size, fixed compensation, resonance etc. On the other hand, active filters are the new filters designed by implementing power electronic technology and can overcome the drawbacks of the conventional filters despite costly. Hence for simple networks, the passive filters can be used. The simple filter circuit is connecting inductor or capacitor across the load. However, the performance is increased by combining both of these. The compensation offered by these devices are discussed below.

2.2.1 A Capacitive or Inductive Filter

Kusters and Moore [8] showed that the instantaneous reactive current i_q can be orthogonally divided into two ways as:

$$i_q = i_{qc} + i_{qcr} \tag{2.23}$$

$$i_q = i_{ql} + i_{qlr} \tag{2.24}$$

where i_{qc} and i_{ql} are instantaneous capacitive and inductive reactive currents, given by,

$$i_{qc} = \frac{\dot{v}(\frac{1}{T}\int_0^T \dot{v}i\,dt)}{\dot{V}^2} \tag{2.25}$$

$$i_{ql} = \frac{\bar{v}(\frac{1}{T}\int_0^T \bar{v}i\,dt)}{\bar{V}^2} \tag{2.26}$$

Here,

$$\dot{v} = \frac{dv}{dt}, \bar{v} = \int vdt$$

and

$$\dot{V}^2 = \frac{1}{T}\int_0^T \dot{v}^2 dt, \bar{V}^2 = \frac{1}{T}\int_0^T \bar{v}^2\,dt$$

The instantaneous inductive and capacitive reactive currents are i_{qcr} and i_{qlr}. Corresponding RMS components are given by,

$$I_{ql}^2 = \frac{1}{T}\int_0^T i_{ql}^2\, dt,\ I_{qc}^2 = \frac{1}{T}\int_0^T i_{qc}^2\, dt \tag{2.27}$$

Similar definitions also apply for rms residual currents i_{qcr} and i_{qlr}.It is shown that,

$$I_q^2 = I_{ql}^2 + I_{qlr}^2 = I_{qc}^2 + I_{qcr}^2 \tag{2.28}$$

The currents i_{ql} and i_{qlr} are orthogonal and the same is applicable for i_{qc} and i_{qcr}. For linear loads with sinusoidal source, i_{ql}, i_{qc} are zero and i_{qlr}, i_{qcr} are equal, opposite in nature. Inductive load compensation is done by connecting C in shunt and vice versa. For a non-sinusoidal source i_{ql}, i_{qc} are zero . The inductive and capacitive reactive currents may be unequal, and both positive or opposite in sign.

2.3 Reactive Power Compensation in Three Phase Circuits

2.3.1 Instantaneous Reactive Power (IRP) Theory

This was proposed by Akagi et al [9] in 1984. They used Clarke's transformation and the $\alpha - \beta$ components defined from

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{2.29}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2.30}$$

The instantaneous power in the three phase circuit is given by

$$p(t) = v_a(t)i_a(t) + v_b(t)i_b(t) + v_c(t)i_c(t) \tag{2.31}$$

This is also equal to

$$p(t) = v_\alpha(t)i_\alpha(t) + v_\beta(t)i_\beta(t) + v_0(t)i_0(t) \tag{2.32}$$

where v_0 and i_0 are the zero-sequence voltage and current in the circuit respectively. These are defined as,

$$v_0(t) = \frac{1}{\sqrt{3}}[v_a(t) + v_b(t) + v_c(t)] i_0(t) = \frac{1}{\sqrt{3}}[i_a(t) + i_b(t) + i_c(t)]$$

For a three wire system, (without a neutral wire) $i_0 = 0$. Hence the instantaneous power, p(t) is given by

$$p(t) = v_\alpha(t)i_\alpha(t) + v_\beta(t)i_\beta(t) \tag{2.33}$$

Akagi et al [27] defined the 'instantaneous imaginary (reactive) power' as

$$q(t) = v_\alpha(t)i_\beta(t) - v_\beta(t)i_\alpha(t) \tag{2.34}$$

Combining Eqs (2.32) and (2.33) , we can write,

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} \tag{2.35}$$

It was claimed in [9] that the instantaneous reactive power in the load can be fully compensated by connecting a compensator (with switching devices) without energy storage in parallel with the load. The ideal compensator does not absorb any power and hence the compensator currents are given by

$$\begin{bmatrix} i_{C\alpha} \\ i_{C\beta} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} 0 \\ -q(t) \end{bmatrix} \tag{2.36}$$

Note that $i_{C\alpha}$ and $i_{C\beta}$ are assumed to be currents drawn by the compensator. However, this theory cannot be easily extended to the four wire systems when i_0, and v_0 are non-zero. The single phase situation cannot be treated as a special case of the theory. There is no generalization to systems with more than three phases. An extension of IRP theory to three phase, four wire systems have been proposed in [10] by introducing p-q theory. The p-q theory is explained in detail in the next chapters.

2.4 RPC in MG

Microgrids (MG) are becoming increasingly attractive to consumers and a great number of them will be installed at consumer's sites in the future. Due to the high penetration of distributed generation (DG) units with different types of loads, microgrids can cause power quality and power control issues. Some of them are voltage stability, swells and sags, and power factor improvement which requires reactive power. Various approaches proposed for conventional grid have been adopted for reactive power compensation in microgrids, progressively improved methods and devices were further suggested and applied. Among the devices, the development of CPDs from FACTS technology has made it possible to provide the reactive power compensation dynamically in microgrids. Henceforth, this chapter presents numerous techniques and application of FACTS devices for reactive power compensation in microgrids. Subsequently, the challenges and power quality issues faced in the microgrid are observed and succeeded by a review of compensation methods against these concerns.

2.4.1 Review of RPC in MGs

Microgrids are the systems which operate with different types of loads and micro sources. Due to the high penetration of distributed generation (DG) units with different types of loads can cause power quality and power control issues. Reactive power compensation in microgrids is to be investigated in two ways as shown in Figure. 2.4. One is RPC towards the microgrid in grid-connected mode and in islanded mode. In this situation, the MG RPC can be provided not only by main grid but also by interconnected MGs. The other one is RPC provided by microgrid (working in both modes of operation) towards main grid. Various RPC methods are existing for all these conditions in the literature. However, it is observed that very few solutions are presented to deal with RPC issues, particularly in MG. Hence this work mainly focuses on the RPC issues of the MG when acting independently. This chapter presents literature review of

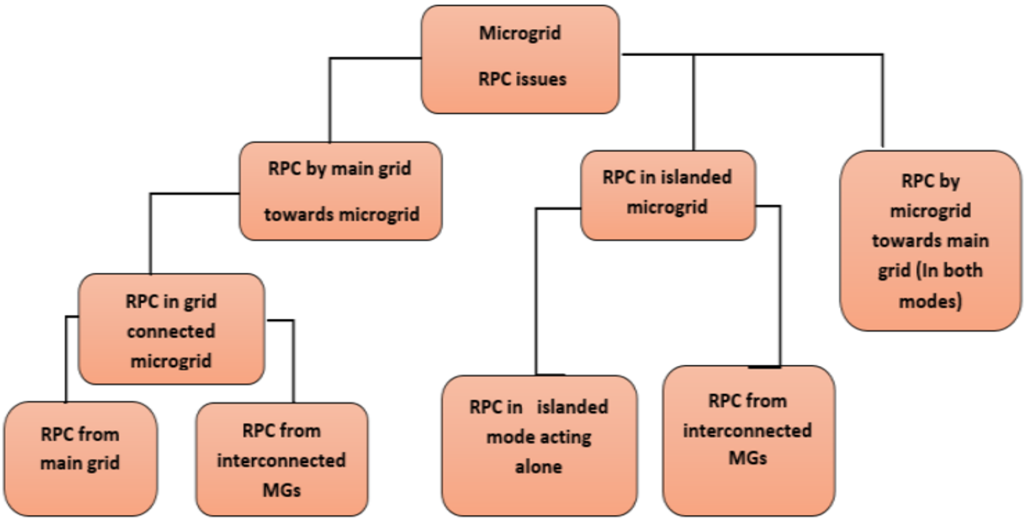

FIGURE 2.4: RPC issues in microgrid

various existing reactive power compensation methods in microgrid in terms of control methods, algorithms and devices as shown in Figure 2.5.

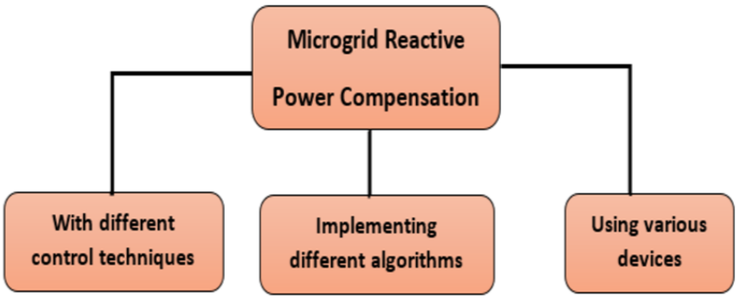

FIGURE 2.5: RPC methods in microgrid

2.4.2 Control Techniques

Many innovative control techniques have been used for enhancing the power quality by providing compensation for the microgrid. The converters used in the microgrid are controlled to deliver desired real and reactive power. Reactive power/voltage and active power/frequency droop concept were mainly used for the power control in the microgrid. The droop control (P/f-Q/V) strategy was downscaled from a conventional grid to low voltage grids in [11]. An improved (P/f-Q/V) control was used to compensate for the imbalance load condition in [12]. A new Adaptive Notch Filtering (ANF) approach was applied without PLL to provide voltage regulation and reactive power control [13]. Co-ordinated P-Q control from DG units to the utility grid by changing voltage amplitude and phase of PWM converter was presented in [14]. Furthermore, the current balance control, in addition to P-Q control, was discussed in [15]. In [16], the effect of load & nature of DG source along with V/f-P/Q control was considered. It has been established that in grid-connected mode, the microgrid can be used for reactive power control, thus transforming its operation into static VAR compensation besides acting as an energy source [17]. Even in autonomous mode, real and reactive power balance can be achieved using node voltage regulation [18]. Power converter building block for sliding mode control of active and reactive power [19], a neural controller in parallel with the PI controller for improved droop control [20] were designed to provide RPC. Reactive power regulation by cooperative control of electronic power processors was suggested in [21]. P/f-Q/V droop control was modified to comply with inertial and non-inertial nature of DG sources [22]. The droop controller design based on three features, current (power) decoupling, the first-order inertia, and droop control was presented in [23]. Instantaneous P-Q theory for reactive power compensation was introduced in [24]. Reactive power allocation (RPA) strategy based on phasor analysis for P-Q management was given in [25]. Reactive power based control against wind flow swings in WECS based microgrids was presented in [26]. Direct P-Q control for micro-hydro ECS [27], direct/inverse droop control of active and reactive power control in both interconnected and islanded microgrids [28] were the other suggested control methods. Harmonic compensation in addition to reactive power compensation using droop control was presented in [29]. P-Q control using Finite Hybrid Automata (FHA) including droop control for switch-mode microgrids was discussed in [30]. Lyapunov current control of P-Q was used to give superior performance over conventional PI or resonant control for microgrids [31]. Dubbed Generator Emulation Controls (GEC) were incorporated to allow

DG inverters to provide voltage regulation support, reactive power compensation, and fault ride-through effectively in microgrids [32]. Instantaneous reference current generation avoiding the usage of PLL and PARK's transformation blocks [33] was provided to enhance P-Q control. However, PARK's transformation with decoupled active and reactive currents was applied to obtain independent P-Q control in [34]. Voltage regulation with sliding mode control to provide reactive power compensation was discussed in [35]. The dynamic reactive power compensation of a microgrid with different photovoltaic permeability was proposed in [36]. Droop control of Island microgrids in [37], bidirectional current control of DC microgrid connected to AC microgrid in [38] were presented. Back-to-back voltage source converter (BTB-VSC) was used to regulate bi-directional power flow through a DC link [39]. Flexible ABC theory - Lagrange optimization was applied for reactive power compensation of a distribution microgrid [40]. Q– $\dot{V}$ droop control method with $\dot{V}$ restoration mechanism was proposed to improve reactive power sharing [41]. Reactive power-sharing errors using the conventional droop control was reduced by injecting a small real power disturbance in [42]. A new consensus-based P-f and Q-$\dot{V}$ droop control was suggested in [43]. A model predictive control based dynamic voltage and VAR control were presented in [44, 45]. Besides, inspired by the conventional P-f droop control, a $\int Q$ dt - V droop control was proposed in [46] by reducing the voltage proportional to the integration of the reactive power. This control mainly reduces the errors in reactive power sharing. Microgrid acting as APF to provide harmonic reactive power compensation using model predictive control was given in [47]. A review of optimal active and reactive power flow in microgrids was presented in [48]. Power flow analysis and different control modes of DGs, such as droop, PV, and PQ, in an islanded MG, were described in detail in [49, 50]. Reactive power compensation issues in interlinking converters of microgrid were caused by a phenomenon known as a limit cycle. The appearance of the limit cycle was eliminated by using non-linear hysteresis control given in [51]. A tariff based fuzzy logic controller was designed for microgrids with reactive power and harmonic compensation as main functions in [52]. The above control techniques starting from droop control, inverse droop control, control with and without PI controller, with and without PLL, various novel proposed control schemes as shown in the Figure 2.6 were applied in

TABLE 2.1: Various reactive power compensation methods

Method	Compensation technique
Control techniques	[31], [32], [33], [34], [35], [36], [38], [39], [40], [41], [43], [44], [46], [51], [52]
Algorithms	[53] [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65],
Devices	[66], [67], [68, 69], [54], [70],[71],[72], [73], [74],[75] [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92–94], [95], [96], [97], [98–100], [101], [102], [103], [104], [105], [106], [107], [108]

a microgrid to provide reactive power compensation.

2.4.3 Algorithms

The following algorithms to provide RPC in MG were implemented by various researchers in providing reactive power compensation in microgrids. The algorithms were micro-genetic algorithm [53], flux charge current-limiting algorithm [54], applied micro-genetic algorithm with minimal real power loss [55], strategic frame based energy management [56]. Sensorless algorithm for the decoupled control of torque and reactive power in WECS based microgrid [57], and conservative power theory for voltage unbalance and reactive power compensation [58] were discussed. Furthermore, the smart control algorithm for P-Q management [59], the power control loop and voltage-current close loop control algorithm for combined PQ and droop control [60] were proposed. The ranking algorithm to withstand maximum P-Q load abilities [61], the phasor pulse width modulation algorithm [62], the multi-objective optimal power flow algorithm for multi microgrids [63], and the randomized gossip-like algorithm [64] were suggested to enhance the power quality in microgrids. A distributed control algorithm was proposed to solve reactive power compensation problem in microgrids in [65]. Thus, various proposed algorithms for providing reactive power compensation in PV and wind-based microgrids are listed above and shown in the Figure 2.6. The devices that are used to provide RPC as shown in the Figure 2.6 are discussed in the next section.

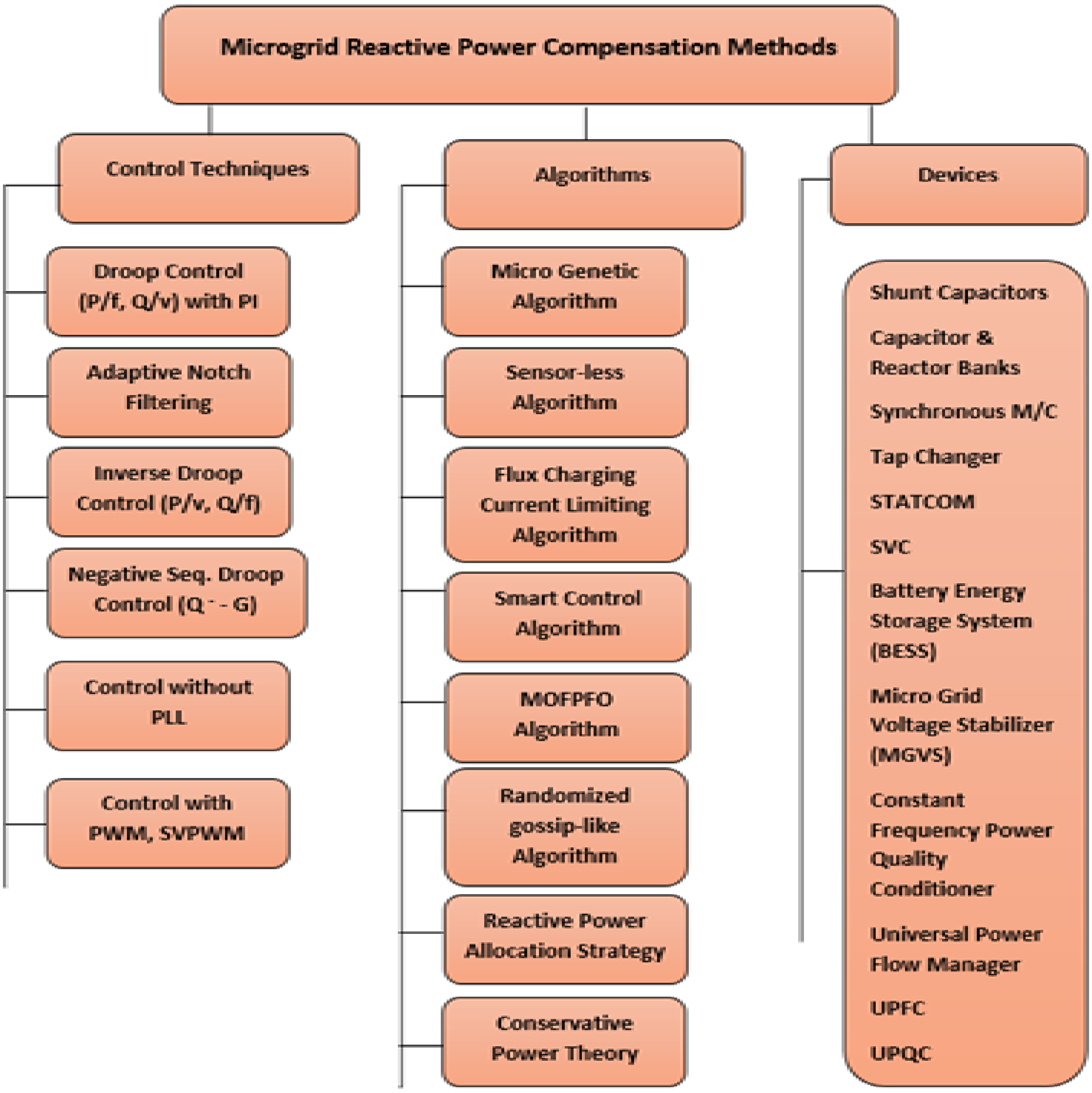

FIGURE 2.6: RPC techniques in microgrid

2.4.4 Devices

The power quality problems in microgrids are to be mitigated by providing harmonic, reactive power and unbalanced compensation. Otherwise, power quality of microgrids is adversely affected. In addition, they cause disturbance to other consumers and interference in nearby communication networks. Existing survey suggests the application of different compensation devices as a solution to reactive power compensation. Usage of capacitor banks, application of TSC and TCR devices of classic technology mitigates some of the aforementioned power quality problems. Conventional passive LC filters were used to mitigate harmonics and reduce the number of capacitor banks while improving power factor. However, the main drawbacks like bulkiness, resonance, fixed compensation are the deterrents of the classical methods. Power electronics based Flexible AC transmission systems, also known as FACTS devices, have been developed and seemingly provide a powerful solution to compensation. Initially, FACTS based reactive power compensation in WECS was discussed in [66]. The power electronic interfacing to ensure power quality in microgrids was introduced in [68, 69]. The conventional grid reactive power compensation FACTS devices were suggested to be implemented in microgrids in [53]. A three-phase four-wire grid-interfacing power quality compensator was proposed in [54].

Few devices proposed for compensation were, D-UPFC for voltage sag/swell control [70], shunt active power filter [71] for VAR compensation, static synchronous compensator (STATCOM), battery energy storage system (BESS) [72], and voltage and frequency controller (VFC) with a DC chopper to control the reactive and active power [73]. Combination of DSTATCOM and DG in grid connected mode [22], Dynamic voltage regulator [74], UPFC [75] were proposed to provide power quality compensation. Reactive power management in a hybrid electrical station (photovoltaic and hydro turbine) and diesel generators constituting a microgrid can be achieved when DFIG was connected to the microgrid [109]. Similarly, a combination of synchronous generator and induction generator was suggested in parallel operated micro-hydro plants [110] for providing compensation. DFIG-WECS with PQ based PWM converters was suggested in [76]. Distributed switching power processors and static reactive compensators [77], Dynamic power limiter with matrix converter at PCC [78], DSTATCOM for VAR regulation [79] were the other suggested power electronic interfacing devices in microgrids. A microgrid voltage stabilizer (MGVS) [80], microgrid with wireless technology (ZigBee, 2.4GHz) [81] were designed and recommended for active-reactive power control and coordination. Multi-function devices like constant frequency UPQC with matrix converter [82], universal power line manager consisting UPQC, UPFC and matrix converter [83] were suggested for mitigation of different power quality problems. VAR compensator was applied in parallel operated the wind or hydro microgrid along with self-excited induction generator [111]. UPFC for combined conventional and DG grid compensation [87], UPQC for power quality improvement [98–100], Kalman filter in WECS [84] for VAR control, Battery storage along with micro-wind energy generation system (μWEGS) [85] for voltage support were presented for various compensation methods in microgrids. The combination of SVC and APF in [86], UPFC in microgrids incorporated with Hamilton – Jacobi – Bellman Formulation [88] has given reactive power support in microgrids. A comparison has been made on reactive power - voltage regulation between SVC and static capacitors in [89]. Smart microgrid with power line communication modem (PLC modem) for reactive power compensation coordination was discussed in [90]. Nine IGBT's based UPFC topology [91], STATCOM as a custom power device (CPD) [92–94], SVC in LV grids with TCR and TSC [95] were suggested for reactive power compensation and voltage fluctuation mitigation in microgrids. Distribution level power electronic devices like STATCOM, SSSC, UPFC, multi-terminal and back-to-back converters for DG connected network compensation were additionally discussed in [96]. UPQC for interconnecting PV modules to grid with power angle control, thereby enhancing power quality was discussed in [97]. Similarly, enhanced UPQC with different modeling aspects and energy systems [101], and a multi-converter UPQC (MC-UPQC) using fuzzy logic controller [102] provide RPC. Implementation of three phase four wire distribution UPQC [103], comparison between STATCOM and UPQC for asymmetrical faults of WECS [104], UPQC for intelligent islanding and seamless reconnection of microgrids [105], advanced UPQC for grid integration and VAR control [106], H ∞ controller for series unit voltage and shunt unit current track compensation in microgrids [107], improved iUPQC controller as STATCOM for grid voltage regulation and reactive power support [108] provide a review of UPQC in providing power quality in microgrids. Power quality problems in conventional grid-connected with renewable energy sources can be solved with the application of FACTS devices [67, 112]. UPQC has been designed by Vinod Khadkikat.et.al. to mitigate power quality issues in the conventional distribution system. Utilization of UPQC using various control approaches has been discussed in detail [113], [114]. From this, the device UPQC is well proven to be a custom power device in a conventional distribution environment. Later, the application of APFs in providing power quality compensation was discussed for DG connected main grids by Khadem.et.al. In all the situations, [115], [116], [117], [118], UPQC was used to provide compensation to the grid. Table. 2.1 gives the summary of the various methods in terms of control techniques, algorithms, devices for providing RPC.

2.5 Gap in the Research

The power electronic interfacing towards DG systems gives rise to some of the serious power quality problems, such as, the reactive power requirement, unbalance and generation of harmonics that pollutes the power distribution system. Therefore, current research is to cope up with the expanding DG or microgrid system and mitigation of these concerned issues. Recent trends are geared towards the realization of multitasking devices which can tackle several power quality problems simultaneously. Conventional devices used for power quality improvement have fixed (tuned) frequencies and will not perform properly under changing system configurations and /or variable (nonlinear) load conditions. Furthermore, the performance of the system can be very effective if the source supplies only the active power whereas reactive power should be locally supported.

Custom Power Devices (CPDs) can operate in this direction, by functioning at the point of installation without considering the power quality status of the entire system. However, the existing literature presents the application of these devices for providing PQ compensation towards main grid. In grid-connected mode, these devices are implemented along with MG to meet the compensation requirement of the main grid. In such cases, the VSCs of the APFs are driven by DG connected MG. In turn, the resultant system is connected to the conventional grid to mitigate its power quality problems. i.e., the function of MG, in this case, is limited to support the DC link of the VSCs of UPQC only. To get operated, UPQC takes the support of DG systems (PV generating system) by replacing its DC link. Even in islanded mode, the function of the MG is to support UPQC DC link whenever required. However, the PQ compensation devices to tackle PQ issues in MG are not focused. Hence, the thesis considers the condition of a microgrid (i.e. islanded mode) which is operating separately from main grid and acts as a mini power system. In such case, there is no reference for frequency or voltage and the MG has to maintain its power balance independently without any support from the main grid. In this condition, it is very difficult to meet reactive power and other compensation requirements due to tightly coupled generation and distribution that further necessitates a multi-functioning device to handle these issues.

In addition, it is also required to optimize the performance of the system by providing multi-tasking (Voltage regulation, Reactive power compensation, Harmonic compensation etc.) using a single solution. Hence, with the motivation from conventional compensation strategies discussed earlier, the CPDs are implemented in the MG. The two considered CPDs are DVR and DSTATCOM for voltage and current compensation. Further, these two devices are enhanced with APF technique to mitigate harmonics. Later, a multitasking device, UPQC is imported into microgrid distribution environment to handle the concerned power quality issues.

The proposed system is completely based on grid free environment where a mini power system can be created with the help of microgrid (comprising various DERs like wind, solar etc.) and the device UPQC is incorporated to take care of the power quality problems of this small community or island without any support from the grid. In addition, the modified topology of UPQC is proposed with a combination of enhanced DVR and DSTATCOM. The design of the UPQC will be restricted to the operating conditions of the particular system only and the ratings of the APFs are also downscaled to lower distribution level from utility grid level making the structure cost-effective.

2.6 Conclusion

Power distribution system is becoming highly vulnerable to different power quality problems as the penetration level of small/large-scale renewable energy systems installed at distribution as well as transmission levels is increasing significantly. This integration of DERs in a power system is further imposing new challenges like RPC to the electrical power industry. To maintain the controlled power quality regulations, providing compensation at all the power levels is becoming a common practice. In this regard, initially, the basics of reactive power and compensation in various electrical networks are studied and presented in this chapter. Later, a review of different algorithms implemented, control techniques applied and devices used to provide RPC is highlighted and presented. From the literature, the demand for a multitasking device like UPQC to mitigate multiple power quality issues is identified and recommended.