# Chapter 1

# Introduction

Electrical practices for the entire power system industry are tremendously changing and these progressions will mark an evolution of new concepts and strategies in the future, particularly concerning generation, and operation of the power systems. The renewable energy based distributed generation is taking a lead in the present and continue to into future power generation. DGs based on solar, wind resources and microturbines are contributing heavily to the electricity generation. Therefore, the emphasis is on distributed generation (DG) systems with the integration of renewable energy systems. A microgrid (MG) is a small-scale power network designed for a low voltage distribution system to provide supply for a small community/island. The power generation is mainly based on renewable energy resources. The major elements of MG would be distributed generation units like PV and wind generators, storage devices, different loads, and power converters for operation and control of the microgrid as shown in the 1.1. The two operating modes of the MG are grid-connected and islanded mode. In grid-connected mode, MG is connected to the conventional grid thereby allowing power exchange as shown in 1.2. In individual/islanded mode MG is operated independent of the conventional grid. A simple islanded microgrid is represented in 1.3. As the penetration of RES into the main grid is gaining more attention, simultaneously the power quality (PQ) challenges are also to be focused. The power electronic equipment facilitates the integration of these RES with the maingrid as shown in 1.4 in compliance with PQ standards. However, interfacing using power electronic equipment create a plethora

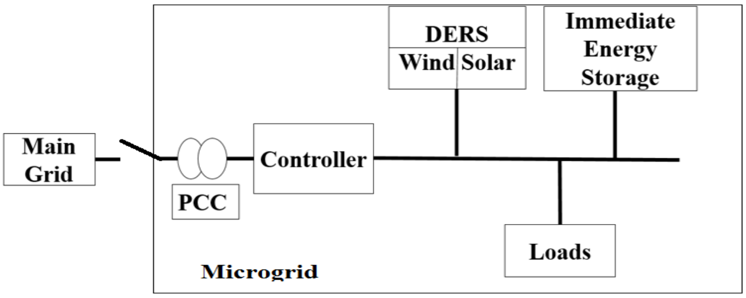


Figure 1.1: General structure of a microgrid

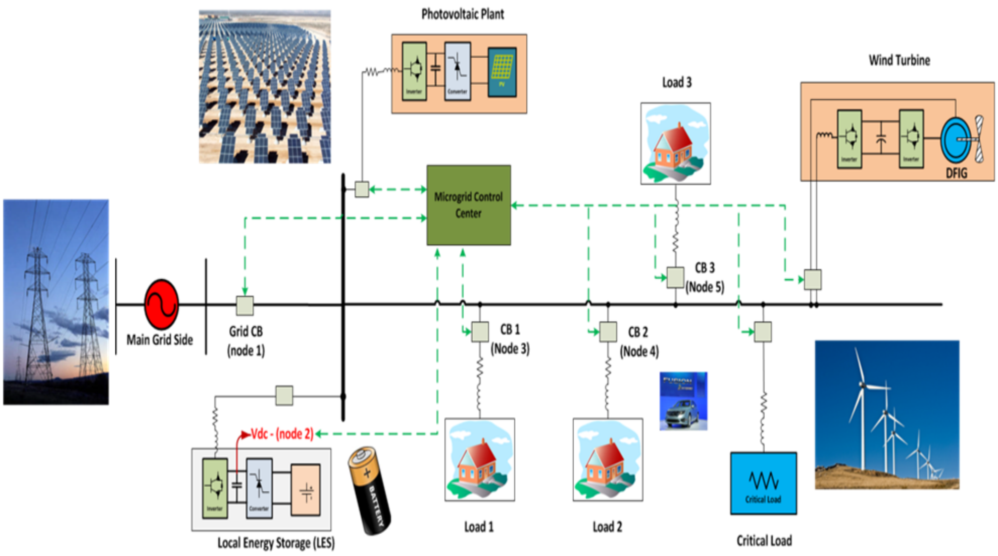


Figure 1.2: Grid interconnected microgrid

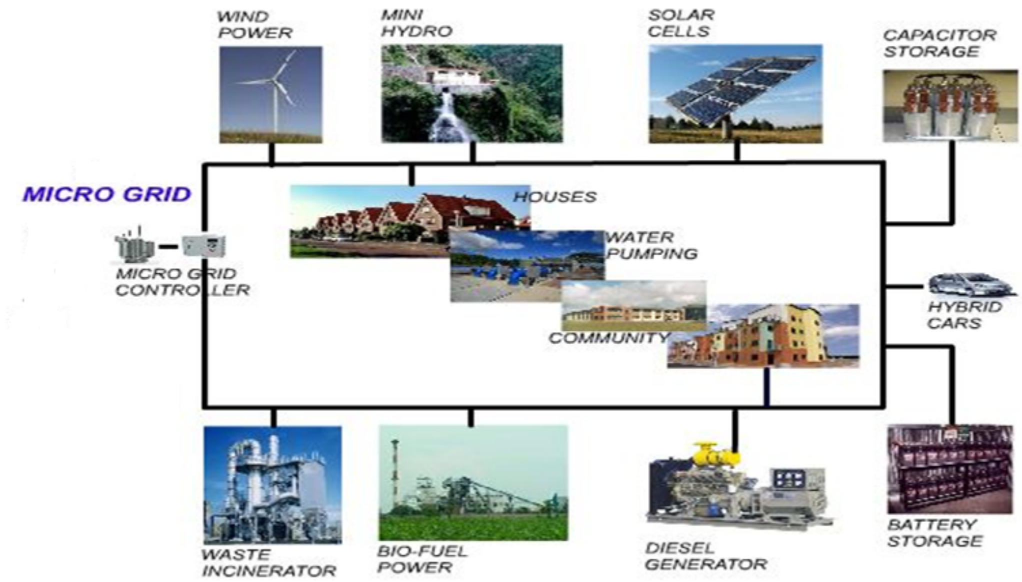


Figure 1.3: Islanded microgrid

of power quality problems such as consumption of volt-ampere reactive (VAR), introducing current and voltage harmonics etc. The switching of this power electronic equipment at higher frequencies cause harmonic injection in voltage and current that deteriorate the performance of the power distribution systems. On the other hand, Custom Power Devices (CPD) such as STATCOM (Static Compensator), DVR (Dynamic Voltage Restorer) and UPQC (Unified Power Quality Conditioner) is the latest development of interfacing devices between the distribution supply (grid) and consumer appliances. The aim of these CPDs is to provide compensation for reactive power and harmonics resulted from voltage/current disturbances. Therefore the aim of the present research to explore the power quality improvement of microgrids using CPD's.

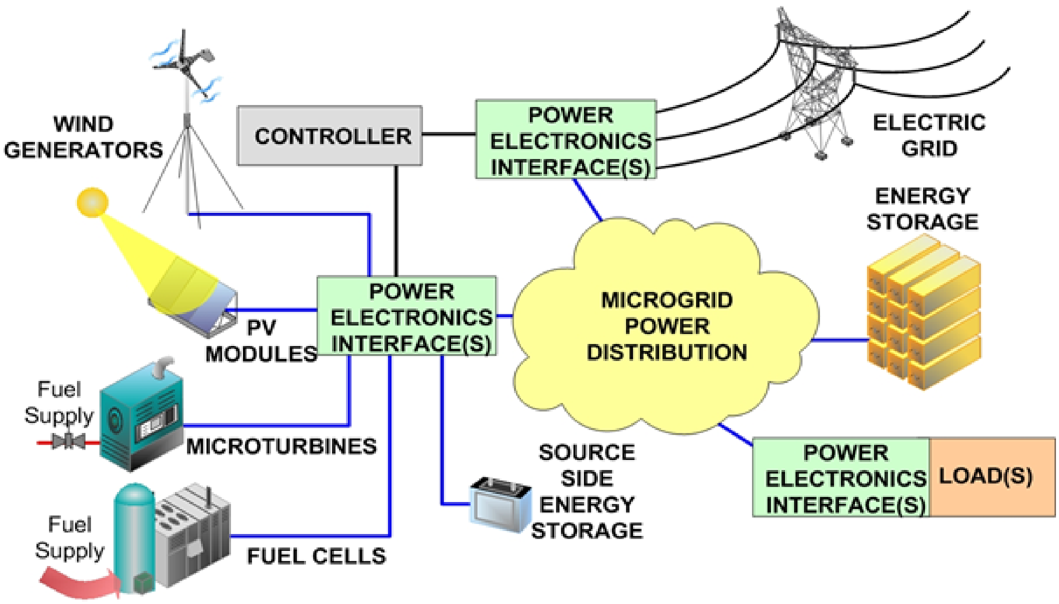


FIGURE 1.4: Microgrid employing power electronic interface

### 1.0.1 Distribution Generation Based Microgrid

Distributed generation, is also called as load center generation or decentralized generation. It generates electricity near to the load center using the available energy resources. Wind generators, photovoltaic panels, fuel cells and microturbines – just to mention a few –are some forms of electricity generation involving the exploitation of distributed sources through the concept of Distributed Generation (DG).

A microgrid is a small-scale power supply network that is designed [3] to provide a power supply

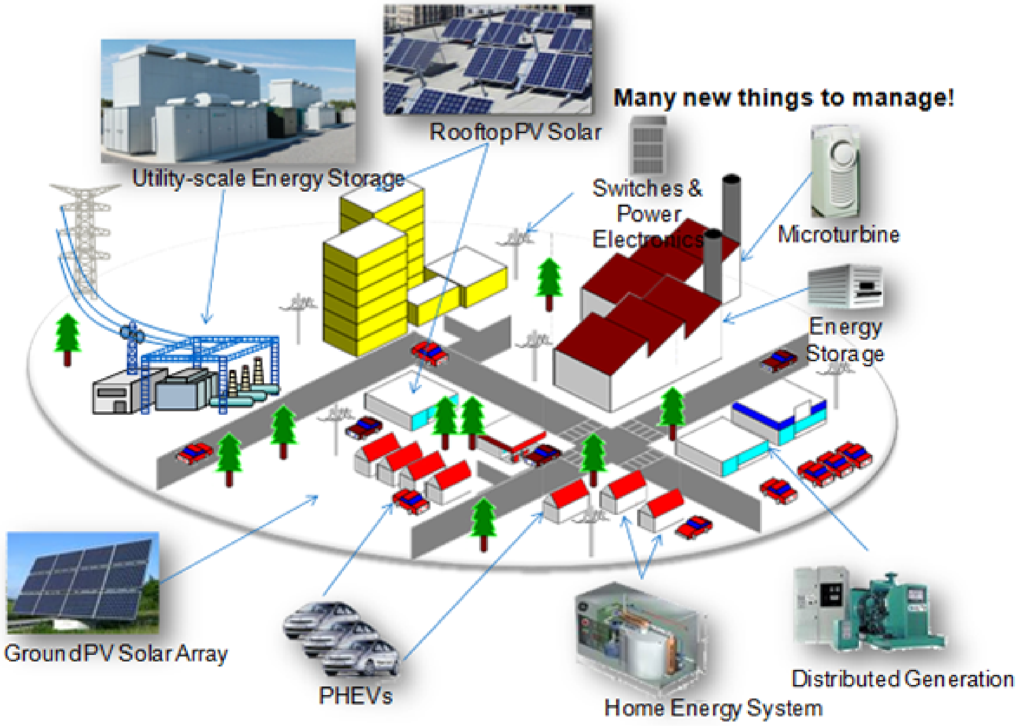


FIGURE 1.5: A typical DG connected microgrid

for a small community mainly based on renewable energy sources as shown in the Figure 1.5. It is a portion of the low-voltage power distribution network that is managed autonomously from the rest of the network [4], to improve efficiency, and pursue specific economic interests. The excess power from the microgrid can be exchanged with the utility grid. The size of the microgrid may range from a housing estate to municipal regions. However, the PQ problems are also of increased concern. Therefore, the studies in this thesis are limited to various PQ disturbances in the microgrid system which based on the solar and wind energy systems.

## 1.1 Power Quality Issues in Microgrid

The definition of power quality(PQ) given in the IEEE is given by "Power quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment." The IEC definition of power quality, given in IEC (International Electrotechnical Commission) 61000-4 30, states "Characteristics of the electricity at a given point on an electrical

system, evaluated against a set of reference technical parameters." The recent definition of PQ is "the ability of the electric utilities to supply electric power without interruption.
Power quality is considered as a combination of current [3] and voltage quality. Any kind of change in actual voltage/current from reference is referred as a PQ issue.

The different PQ problems include fundamental frequency deviations, interference, transients, low p.f caused due to source/load side changes. Among these events, voltage and current disturbances and harmonics are dominant and require more attention. Microgrids are the systems consisting different kinds of sources and loads which operate with different types of loads and micro sources [5]. Due to the high penetration of distributed generation (DG) units with different types of loads can cause PQ problems. The traditional droop control techniques cannot be applied for nonlinear loads as they can not provide proper harmonic mitigation. Hence, in MG environment, the reactive power balance is a difficult task when the connected load is of nonlinear type. Among the DG sources, PQ issues related to solar and wind energy systems are the major concerns here. Therefore, a brief discussion on various power quality problem has been introduced here.

### 1.1.1 Major Power Quality Problems

The important power quality problems at the distribution level are discussed below (Dugan et al, 1996, Schlabbach et al., 2001; Stones and Collinson, 2001; Sankaran, 2002).

- **Voltage Sag (Dip):** Sags are short-duration reductions in the RMS voltages between 0.1 and 0.9 pu. The duration of voltage sag may vary between 5 cycles to a minute.
- **Voltage Swell:** The increase of voltage magnitude between 1.1 and 1.8 pu is called swell. The most accepted duration of swell is from 5 cycles to a minute. Swells are not common as sags.
- **Transient:** It is an undesirable momentary deviation of the supply voltage or current, which can be impulsive or oscillating in nature. An impulsive transient is a sudden, no power frequency change in voltage or current which is unipolar in nature.

- **Flicker:** Flicker has been described as "continuous and rapid variations in the load current magnitude which causes voltage variations." The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived to flicker by the human eye.
- **Waveform Distortion:** It is a steady state deviation in the voltage or current waveform from an ideal sine wave at a fundamental supply frequency, characterized by the spectral content of the deviation.
- **Harmonics:** Harmonics are sinusoidal voltages or currents with frequencies that are integer multiples of the power system (fundamental) frequency (usually, f - 50 or 60 Hz). For example, the frequency of the nth harmonic is (nf). Periodic nonsinusoidal waveforms can be subjected to Fourier series and can be decomposed into the sum of fundamental component and harmonics.
- **Unbalance:** When voltages of a three-phase system are not identical in magnitude and/or the phase differences among them are not exactly 120 degrees, voltage unbalance occurs.
- **Undervoltage:** The under-voltage condition occurs when the RMS voltage decreases to 0.8-0.9 pu for more than 1 minute.
- **Overvoltage:** Over voltage is defined as an increase in the RMS voltage to 1.1-1.2 pu for more than 1 minute.
- **Interruption:** An interruption occurs when the supply voltage or load current decreases to less than 0.1 p. u. for a period of time not exceeding 1 min.

  Some of the important power quality problems are shown in the following Figure 1.6

Various power quality problems and their causes in microgrid are also listed in Table 1.1

### 1.1.2 PQ Issues in Solar Photovoltaic (PV) System

The DC power is generated from PV systems based on solar insolation and is connected to the main grid via converters. A recent trend is rooftop mounting of solar systems even for household

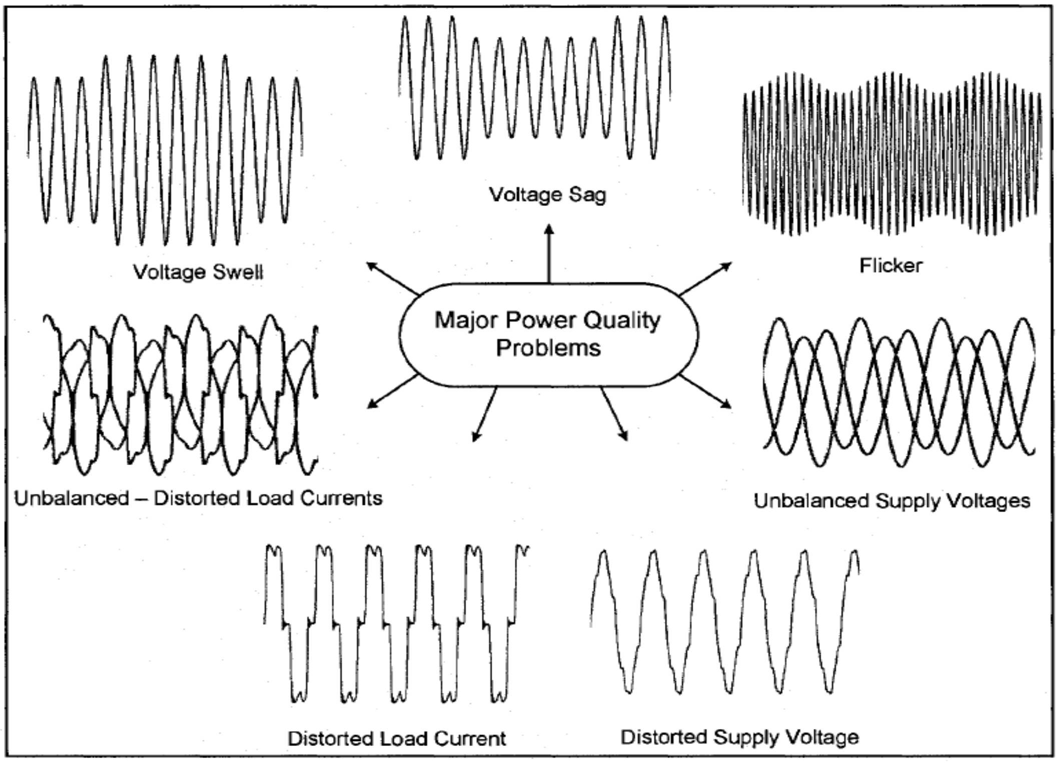


FIGURE 1.6: Pictorial view of major power quality problems on distribution level

power supplies with the applied net metering. A typical solar PV size lies from 2 to 6 kW and has almost free incremental cost. PV solar technology is encouraged mainly for its environmental friendliness. One drawback is a requirement of grid support due to its intermittence. However, a PV -Wind combined MG can be proposed to be supported in individual mode. Similarly, power

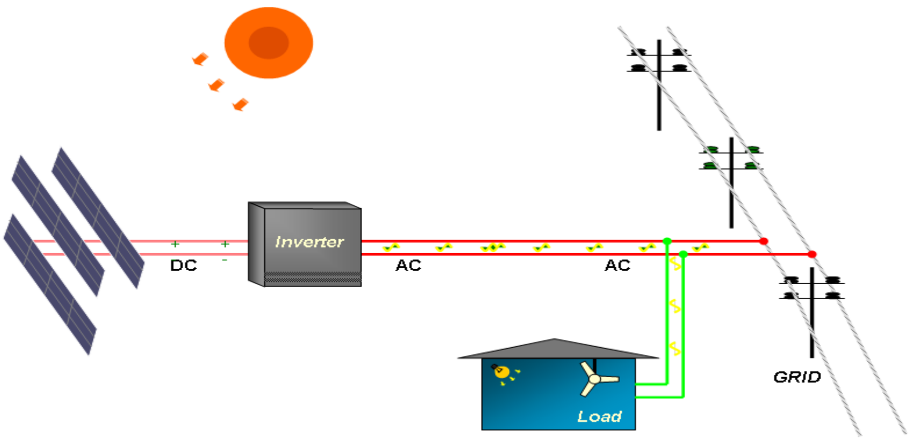


FIGURE 1.7: General structure of grid-connected PV system

quality maintenance of PV gains more importance to increase its efficiency. This includes the PV modules, the filtering and the inverter controlling mechanism. The continuous variations in solar

TABLE 1.1: Power quality problems and their causes in microgrid

| Broad Categories | Specific Categories | Methods of Characterization | Typical Causes |
|---|---|---|---|
| Transients | Impulsive | Peak Magnitude, rise time and duration | Lightning strike, Capacitor switching |
| | Oscillatory | Peak Magnitude, frequency components | Line or capacitor or load switching |
| Short duration voltage variation | Sag | Magnitude,duration | Single line-to-ground faults |
| | Swell | Magnitude,duration | Single line-to-ground faults |
| | Interruption | Duration | Temporary (self clearing) faults |
| Long duration voltage variation | Undervoltage | Magnitude,duration | Switching on loads, capacitor deenergization |
| | Overvoltage | Magnitude,duration | Switching off loads, capacitor energization |
| | Sustained interruptions | Duration | Faults |
| Voltage imbalance | | Symmetrical components | Single phase loads, single phasing condition |
| Waveform distortion | Harmonics | THD, Harmonic spectrum | Adjustable speed drives and other nonlinear loads |
| | Notching | THD, Harmonic spectrum | Power electronic converters |
| | DC offset | Volts,Amps | Geo-magnetic disturbance, half-wave rectification |
| Voltage flicker | | Frequency of occurrence, modulating frequency | Arc furnace, arc lamps |

insolation and temperature effects the PQ of LV grids and may lead to disconnection at PCC due to voltage limit violations. The Figure 1.7 shows the general block diagram of a grid-connected PV system. However, the connection of nonlinear loads rises harmonics in addition to output voltage changes due to change in input irradiance. All these issues cause PQ problems in PV systems which further necessitates compensation.

### 1.1.3 PQ Issues in Wind Energy Conversion System

WECS based generation is growing rapidly based on its specific economic interests compared to other types of generations. The WECS generation may range from few kW-MW with their large/small size. Sometimes they can be directly connected to the distribution system. WECS also supports PV in the formation of microgrids. Figure 1.8 shows a simplified representation of different wind energy systems connected to the grid. From the design perspective, some configurations involve the generators being directly connected to the grid via a transformer and some, using power electronic interfaces. Many challenging issues are identified in wind generating system when it is integrated into the electric grid via power electronic interface [6]. In addition, the converter-based systems have the main drawback of injecting harmonics into the system. The WECS mainly suffers voltage regulation problems due to change in its wind speed. All these recommend integration with PV or other DG to get support. Even the two connected DGs compliment each other, sometimes a situation arises that both DGs face the problem of change in corresponding inputs simultaneously. All these suggest that the new wind farms must be designed with the compensation for reactive power and harmonics injected to ensure voltage and reactive power control in order to maintain system stability.

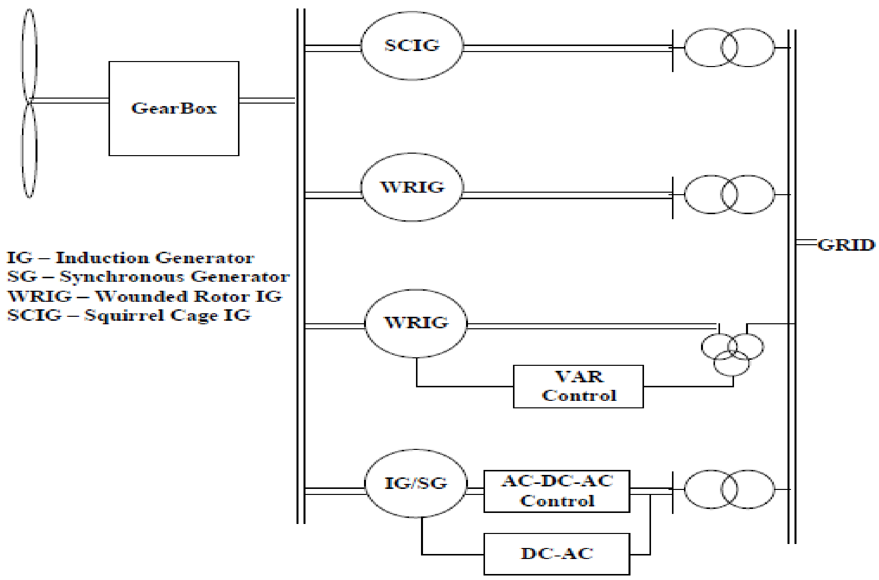


FIGURE 1.8: Different types of wind energy system

## 1.2 Power Quality in terms of Voltage Quality

Mostly, the term power quality mainly contributes to voltage quality. However, the power P is actually the product of voltage and current. The voltage parameter can only be controlled by various power system parameters which in turn control the remaining. Hence the maintenance of power quality is devoted to maintaining voltage within norms [7]. The power system quantities in the AC networks are designed to be operated with a sinusoidal form with the fundamental frequency. Any deviation from this is referred as PQ problem. Thus, maintenance of voltage within limits also addresses other PQ problems indirectly.

### 1.2.1 Reactive Power Compensation and Voltage Sag/Swell

Reactive power is a quantity that has become fundamental to the understanding and analysis of AC electric power systems. Our power system operates on AC system and most of the loads used in our daily life are inductive in nature which requires reactive power. Additional reactive power requirement is observed at the load side to maintain voltage profile or power factor improvement. Therefore reactive power is a very important concept from an electrical perspective. RPC or VAR compensation is defined as the management of reactive power to improve the performance of ac power systems. In general, the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. In load compensation, the objectives are to increase the system power factor, to balance the real power drawn. Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission/distribution line. In both cases, the reactive power that flows through the system can be effectively controlled. Reactive power compensation in power systems also improves the stability of the ac system by increasing the maximum active power quantity.

Series and shunt compensations are used to modify the natural electrical characteristics of AC power systems. Series compensation modifies the transmission or distribution system parameters, while shunt compensation changes the equivalent impedance of the load. In both cases, the reactive power that flows through the system can be effectively controlled improving the performance of the overall ac power system. 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. The most stressing situation is observed when the micro-grid load is inductive in nature and RPC is predominant as in [10]. In islanded operating condition, the microgrid has to maintain the power balance independently of the main grid as it does not provide voltage and frequency references. Lack of infinite bus, tightly coupled generation and consumption, and the existence of nondispatchable intermittent renewable power sources demand new techniques for VAR compensation in the microgrid. In a grid-connected mode, with linear and non-linear loads, the reactive power sharing is also found to be challenging. The need to adjust reactive power compensation is mainly based on voltage control within acceptable bounds about the desired steady-state value to provide quality service to consume loads. In turn, it regulates the voltage profiles in the network to prevent unnecessary flows of reactive power in the system. The mathematical analysis of the relation between reactive power compensation and voltage level as follows: Reactive power flow (Q) is closely related with the voltage control. The apparent power S (kVA) is given by Complex power S is the product of voltage V and the complex conjugate of I i.e

$$S = V_S I^* = P \pm jQ \tag{1.1}$$

Where S is apparent power (kVA), P is real power (kW), Q is reactive power (kVAR). The various compensating equipment (capacitors, FACTS devices, CPD's) mentioned in the above sections 'absorb' or 'generate' reactive power. For inductive loads, the component S is the sum of P, Q with positive Q value. However, for capacitive Q will be negative. Hence the component S is the difference between P and Q. Power P controls the active power which is converted into heat (or) some other form and influence frequency f. Reactive power Q is exchanged between inductive and capacitive loads in the network and influences the voltage in the network. Reactive power flow increases losses. Hence compensation is provided at each bus. The control of various bus voltage is achieved by supplying/absorbing VARs using series (or) shunt compensation.

Note: Compensation of reactive power means supplying/absorbing reactive volt-amperes. The

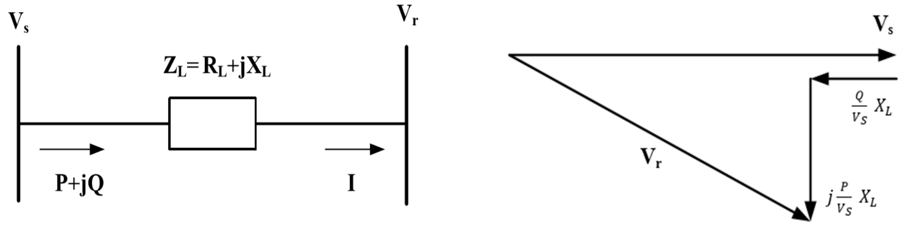


FIGURE 1.9: Line diagram and phasor diagram of distribution system

simple distribution system with its reference voltage (or) source voltage Vs and load voltage $V_r$ with line impedance $Z_L$ and current I is considered as shown in Figure 1.9. The power flow is also indicated. $V_S$ = Sending end voltage, $V_r$ = Receiving end voltage

Drop in the line voltage is

$$\Delta V = V_s - V_r, \tag{1.2}$$

Series impedance of the line/phase is

$$Z = R + jX \tag{1.3}$$

From the line diagram shown in the Figure 1.9,

$$V_r = V_S - IZ \tag{1.4}$$

From eq (1.1), Considering $V_S$ as reference phasor,

$$I = \frac{P - jQ}{V_S} \tag{1.5}$$

$$V_r = V_S - IZ = V_S - \frac{P - jQ}{V_S} Z \tag{1.6}$$

$$V_r = V_s - \frac{P}{V_s} Z + j\frac{Q}{V_s} Z \tag{1.7}$$

Substituting Z from eq (1.3) in (1.2) and simlifying,

$$\Delta V = V_s - V_r = \frac{Q}{V_s} X_L \tag{1.8}$$

If the resistance R is neglected for X >> R then,

$$V_r = V_s - j\frac{P}{V_s}X_L - \frac{Q}{V_s}X_L \tag{1.9}$$

The phasor diagram for the reactive drop due to sag/swell (change in voltage) is shown in Figure 1.9. Hence voltage drop mainly depends on the flow of reactive power Q and reactive power flow in turn controls voltage V. For voltage control, the flow of reactive power in the system should be controlled. The flow of reactive power is controlled by injecting/absorbing required VAR's into the system by means of various power quality compensation methods.

## 1.3 Reactive Power - Harmonics

The system with nonlinear loads connected are also prone to many reactive power issues as the connected loads inject harmonic component into the system in addition to the reactive component at the fundamental frequency and both of these components are wattless in nature even the source voltage is sinusoidal. The reactive components due to the harmonics may not be fully compensated by simple conventional passive filters. Hence the reactive power ($Q_B$) in case of nonlinear loads is redefined by C. Budeanu, a Romanian engineer as:

$$Q_B = \sum_{n=1}^{\infty} Q_n = \sum_{n=1}^{\infty} \sqrt{2}\, V_n\, I_n\, sin\, \phi_n \tag{1.10}$$

where n is a number of harmonic in the distorted component. In general,

$$S^2 \neq P^2 + Q_B^2 \tag{1.11}$$

The apparent power with distorted power ($D_B$) is defined as

$$S^2 = P^2 + Q_B^2 + D_B^2 \tag{1.12}$$

$$
\begin{aligned}
D_B^2 &= \frac{1}{2}\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}[V_m^2 I_n^2 + V_n^2 I_m^2 - 2V_m V_n I_m I_n \, cos(\phi_m - \phi_n)] \\
&= \frac{1}{2}\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}[(V_m I_n - V_n I_m)^2 + 2V_m V_n I_m I_n \, [1 - \, cos(\phi_m - \phi_n)]]
\end{aligned} \tag{1.13}
$$

The power of distortion is zero only if

$$\frac{V_m}{I_m} = \frac{V_n}{I_n} \tag{1.14}$$

and

$$\phi_m = \phi_n \tag{1.15}$$

Due to this, a pure resistor can never have distorted power. The definition given by Budeanu's for reactive power has been approved by ANSI/IEEE Standard 100-1977.

## 1.4 The Power Quality Evaluation Procedure

The PQ problems are of the wide range in which each problem is associated with a number of causes and solutions to solve and improve the equipment performance. However, there exist few general steps to be followed including proper investigation for the problem configured to serve both utility and consumer flexibly. Figure 1.10 gives some general steps for PQ investigation, along with the addressed constraints at each step.

## 1.5 Mitigation Techniques

Voltage sags and short interruptions are demanding 60 % of the overall cost to the power industry. There are two mitigation ways: one is from customer side and the other is from the grid side. If the mitigation is from load side, then that is called load compensation. This makes the consumer's sensitive equipment as safe. The other is to suppress the problems from the grid side. Starting from conventional capacitors, passive LC filters, several compensating devices are used for the mitigation of specific PQ problems. Custom Power Devices (CPDs) such as DSTATCOM, DVR, and UPQC are used to mitigate these concerned issues from both supply and grid side.

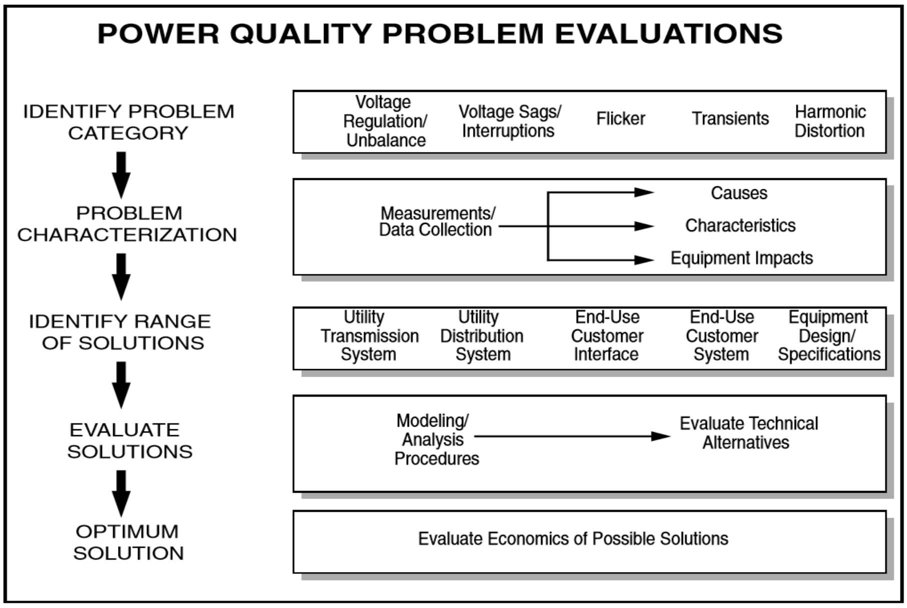


Figure 1.10: Basic steps involved in power quality evaluation

### 1.5.1 Custom Power Devices (CPDs)

The Custom Power (CP) was defined by N. G. Hingorani in 1995. Custom Power originates from the family of power electronics to provide a solution for distribution level power quality problems. This technology utilizes cost-effective high power semiconductor devices such as GTO (gate turn-off thyristor) and IGBT ( insulated gate bipolar transistor) based power electronic devices.

DSTATCOM (Distribution STATCOM) is a shunt -connected custom power device specially designed for reactive power compensation, power factor correction, current harmonics filtering, and load balancing. It is often referred to as a shunt or parallel active power filter (Shunt APF) and it consists of a voltage or a current source PWM inverter. It operates as a current controlled, voltage source and compensates current harmonics by injecting the harmonics generated by the load but phase shifted by 180 degrees.

The DVR is a series-connected custom power device to protect sensitive loads from supply-side disturbances (except outages). It can also act as a series active power filter (Series APF), isolating the source from harmonics generated on the load side. It consists of a voltage source PWM converter equipped with a DC capacitor and a coupling transformer. This device injects a set of controllable voltages in series with the supply voltage through a low pass filter (LPF) and a coupling transformer. This device injects a set of controllable AC voltages in series and in synchronism with the distribution feeder voltages such that load-side voltage is restored to the desired amplitude and waveform, even when the source voltage is unbalanced or distorted. Another device, the active power filter (APF) is the most promising solution to mitigate some of the major power quality problems at the distribution level. They can be classified as a shunt APFs, series APFs, hybrid APFs, and unified power quality conditioner (UPQC). The UPQC, classified as one among the CPDs, is the most versatile power quality enhancement devices which offer advantages of both the shunt and series APFs, simultaneously. The use of any one of these APFs is slowly becoming a common practice in modern industrial installations. On the other hand, the most powerful solution to PQ problems at distribution level is given by active power filter (APF). There are three different APFs: series APF, shunt APF and hybrid of these two which is called as a unified power quality conditioner (UPQC). This UPQC is also categorized as one of the CPD due to its facilitation for combined series and shunt APF functions. Hence the implementation these devices to deal PQ issues has spurred widely not only in industries but also at consumer distribution level. UPQC is the integration of series and shunt active filters, connected back-to-back on the DC side and sharing a common DC capacitor. The series component of the UPQC is responsible for mitigation of the supply side disturbances: voltage sags/swells, flicker, voltage unbalance and harmonics. It inserts voltages so as to maintain the load voltages at a desired level; balanced and distortion free. The shunt component is responsible for mitigating the current quality problems caused by the consumer: poor power factor, load harmonic currents, load unbalance etc. It injects currents in the AC system such that the source currents become balanced sinusoidal and in phase with the source voltages.

## 1.6 Motivation for the Research

Recent trends in the power generation and distribution system shows that the the penetration level of DG into the grid has increased considerably. The power electronic interfacing towards DG systems gives rise to some of the serious power quality problems, such as, the reactive power requirement and generation of harmonics that pollute the power distribution system. Due to the extensive use of nonlinear loads on distribution networks, microgrid customers are facing these power quality problems. Hence end-user appliances are becoming more sensitive to power quality conditions. Therefore, current research is to cope up with the expanding DG or microgrid system and mitigation of these concerned issues. To help the customers, some attempts have been made in the implementation of traditional compensation methods in the past. Switched reactive power compensation (shunt capacitors, shunt reactors) were primarily used to control the steady state system voltages. Dynamic reactive compensation was based on rotating machines, e.g. synchronous condensers. These conventional devices used for power quality improvement have fixed (tuned) frequencies, more in size and will not perform properly under changing system configurations and /or variable (nonlinear) load conditions. Fast response times, lower losses and fewer maintenance requirements of thyristor controlled devices resolved the limitations of rotating machines and DC controlled devices. Recent trends are geared towards the realization of multitasking devices which can tackle several power quality problems simultaneously. Furthermore, it is observed that the performance of the system can be very effective if the source supplies only the active power whereas reactive power should be locally supported. Active filters are developed in this direction, by functioning at the point of installation without considering the power quality status of the entire system. In addition, they optimize the performance of the system by providing multi-tasking (Voltage regulation, Reactive power compensation, Harmonic compensation etc.). In this regard, extensive research on the APF technology (from which the custom power devices are developed) for the mitigation of PQ problems is carried out. With this motivation, CPDs can find significant application in maintaining power quality with active power technology in the microgrid. The three CPDs that include APFs are Dynamic Voltage Restorer (DVR), Distribution Static Compensator (DSTATCOM) and Unified Power Quality Conditioner (UPQC). DVR can solve voltage quality problems whereas DSTATCOM can solve current quality problems. UPQC is a combination of series and shunt APFs (can be designed using DVR and DSTATCOM) can be operated as a multifunction device to mitigate multiple power quality issues. With this motivation, the device UPQC is considered in this thesis to mitigate the PQ issues of the microgrid.

## 1.7 Aim, Objectives, and Organization of Thesis

The main aim of this thesis is

- **To provide reactive power compensation in the microgrid**.
- **To mitigate the voltage sag/swell, flicker problems due to supply and load changes**.
- **To provide harmonic compensation in source currents and load voltages due to nonlinear loads**.
- **To balance the circulating current flow in the source currents due to unbalance loads**.

In order to achieve this, initially, the MG with DERs is to be developed. The requirement of power quality compensation in a microgrid is to be identified due to variations in the supply and loads. The custom power devices DVR, DSTATCOM, and UPQC are able to mitigate all the PQ issues. DVR can effectively mitigate voltage related issues whereas DSTATCOM can compensate current quality issues. UPQC is a combination of these two can be operated as a multifunctioning device to mitigate all the above multiple power quality issues. Hence these three CPDs are to be designed, developed as per the required rating and to be implemented in the MG. The objectives of the thesis are as follows:

1. Study of the conventional methods of reactive power compensation in power systems.
2. Study of the application of a FACTS device especially STATCOM towards reactive power compensation in the conventional power grid.

3. Study of the application of FACTS device UPQC replacing STATCOM and to investigate its effect on reactive power compensation in the conventional power grid and compare the effects of the two FACTS devices.

4. Study of the microgrid and its reactive power deficiencies.

5. Study of the application of the FACTS devices towards reactive power compensation in a microgrid.

6. Study of the reactive power compensation in the conventional grid from microgrid using UPQC.

7. Simulation of the above studies on an example power system and real-time data.

The present research work is presented in eight chapters. In addition to the current chapter, there are seven other chapters that cover mathematical and theoretical analysis of current work. These chapters are as follows:

**Chapter 1:** The motivation, aims, and objectives of the proposed research have been set in this chapter that will be covered in this thesis. Finally, the organization adopted in the thesis have been highlighted.

**Chapter 2:** 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. A literature survey of various reactive power compensation methods in terms of control techniques, algorithms and devices are presented. From the literature, the demand for CPDs to mitigate multiple power quality issues is identified and recommended.

**Chapter 3:** A microgrid with two DG sources (PV and WECS) is developed in this chapter. An accurate model is selected for analyzing the performance of PV based generation and wind energy conversion system (WECS) under different varying conditions. The developed system along with its controllers has been investigated for the real-time data. The actual environmental data like solar irradiation and wind profile have been collected with the help of weather monitoring system of Birla Institute of Technology and Science, Pilani-Hyderabad campus. The record of solar insolation and wind speed during different periods is observed. The variations in the output voltage and active and reactive power flow in each DG with respect to the above variable parameters are considered. The output voltage and P responses in case of PV generating system due to the variation in solar irradiation, the output voltage, and P, Q responses in case of WECS due to the change in wind speed are observed and presented. Due to these frequent variations and also due to the nature of loads (harmonic and reactive) connected, power quality issues like in terms of voltage and current are observed concluding the requirement of reactive power compensation in the MG.

**Chapter 4:** With the continuation of various power quality issues that are resulted from supply and load changes, a compensating device DVR is applied to provide voltage compensation. The performance of the device is initially analyzed for voltage quality compensation in MG in terms of magnitude. Later DVR is enhanced to provide voltage harmonic compensation in addition. The performance of the is also verified for fault ride through condition during symmetrical and unsymmetrical conditions.

**Chapter 5:** In this chapter, DSTATCOM is applied to provide compensation for current quality problems of the MG. Current harmonics and flow of circulating currents problems in MG are analyzed. Further, the DSTATCOM is enhanced with APF feature for mitigating current harmonics due to different nonlinear load conditions. The DSTATCOMs are mainly identified to provide current quality compensation for these current based power quality problems.

**Chapter 6:** A multitasking device, UPQC is designed with a combination of enhanced DVR and STATCOM as series and shunt APFs respectively. Thus the designed UPQC with the modified topology has been analyzed to compensate for the aforementioned PQ issues along with power factor improvement, active power balance, and reactive power compensation.

**Chapter 7:** This chapter discusses the prototype of mini UPQC in MG voltage sag compensation in real-time. In this situation, the MG using PV-WECS emulator is implemented with real-time data of environmental conditions that represent a scale down experimental setup. A prototype of mini UPQC is modeled, designed and connected to the MG emulator to mitigate the voltage sag problem.

**Chapter 8:** Finally, this chapter summarizes the specific contributions of the current study and conclusions gained from this research. Further, future scope and directions for research in this area have also been presented.