Chapter 1

Introduction

1.1 Background

This research focuses on two important issues faced by the modern power distribution system, namely power quality and penetration of renewable sources. One of the mandates for electrical utilities is to supply electric power within prescribed limits of power quality. Power quality issues arise from the grid (utility) side, as well as from the consumer (load) side. Grid side issues include voltage sag, swell, surges, notches, spikes, flicker, unbalance, and harmonics, etc., and load-based issues are reactive power burden, unbalanced loads, harmonic load currents, and excessive neutral currents, etc. Of course, both of these issues can be interrelated; for example, turning on a large load can cause voltage sag. Maintaining power quality in the distribution system is critical to sensitive loads such as hospitals, industrial processes, and manufacturing.

In general causes for the power quality problems are classified into two categories: natural and human-made [1]. Natural causes include lightning, faults, unfavorable weather conditions like storm, equipment failure, etc. Human-made causes comprise of non-linear loads like saturating transformers, power electronic interfaces like variable speed drives and uninterrupted power supplies, electric furnaces, reactive loads, etc. Increased usage of power electronic interface has given rise to power quality issues. Power electronic loads like some of the Adjustable Speed Drives (ASD)s are most sensitive to power quality issues, but they themselves pollute the power quality.

Due to the rise in environmental pollution and depletion of conventional energy resources, there is a need for clean and sustainable energy production. Thus renewable energy sources are to be promoted. Most of these renewable sources, like solar PV and wind, are distributed and non-dispatchable in nature. Thus, it is viable to integrate them directly into the distribution system, which also increases reliability and reduces distribution losses. Increased penetration of renewable sources demands a high standard of power quality, and higher penetration of such sources itself leads to power quality disturbances.

Active Power Filters (APFs) are employed for mitigation of power quality problems in a low tension distribution system. APFs are generally Voltage Source Converter (VSC) based compensating devices, where VSC is used to synthesize compensating voltage or current, which is injected into the distribution system. Series APF compensates for grid voltage sag, swell, unbalance, and harmonics. Thus series APF maintains the sinusoidal balanced voltage at load terminal. Shunt APF is responsible for load reactive power support, eliminating load current harmonics, load unbalance, and neutral current compensation. Thus shunt APF maintains sinusoidal balanced currents with unity power factor at Point of Common Coupling (PCC).

Unified Power Quality Conditioner (UPQC), a combination of series and shunt APFs, is capable of mitigating both supply voltage and load current based power quality problems [2, 3]. In UPQC, series and shunt APFs are connected in back to back fashion sharing a common DC link. A simplified single line diagram of UPQC is shown in Fig. 1.1. In the face of grid voltage disturbance, series APF injects compensating voltage in series using injection transformer and maintains ideal load voltage. Shunt APF injects shunt current to compensate for undesired components of load current and maintains ideal source currents. Interfacing inductors and filters are used at the output of each APF to get the desired quality of voltage and current waveforms.

1.2 Motivation and Problem Description

Though APFs have been traditionally used for compensating power quality issues; recently they have been tried for additional task of integrating renewable sources into distribution system [4, 5], which show the potential of APFs to provide a simultaneous and cost-effective solution to the issues of power quality compensation and renewable energy integration. UPQC has the advantage of compensating a wider range of power quality issues and enhanced support for renewable integration over

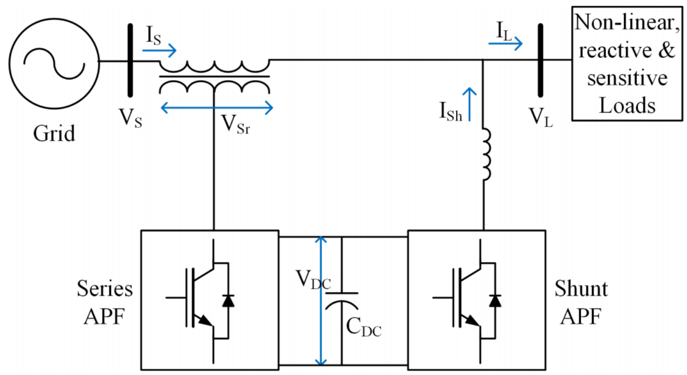

Figure 1.1: Conventional UPQC

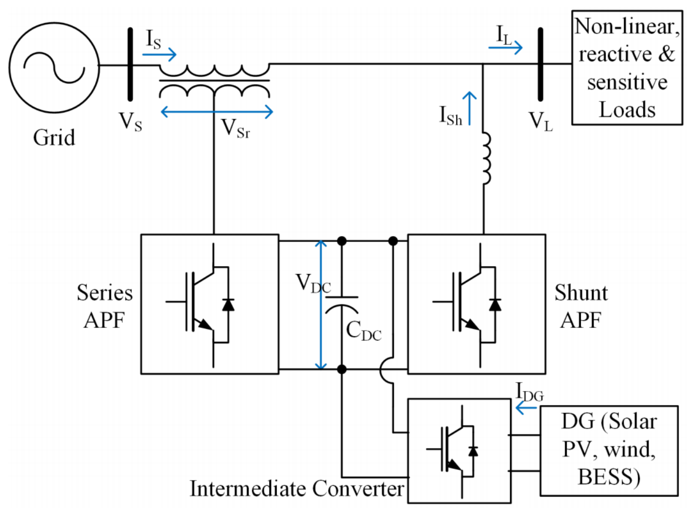

Figure 1.2: Unified Power Quality Conditioner with Distributed Generation (UPQC-DG)

single APF units, and thus have been researched for similar utilization for power quality compensation and renewable integration [6–9].

UPQC-DG is a distinctive configuration of UPQC, especially meant for power quality compensation and integration of renewable sources side by side. In UPQC-DG, Distributed Generation (DG) is connected at DC link (Fig. 1.2). DG can be a renewable source-based generation such as PV or wind, or conventional diesel generator or Battery Energy Storage Source (BESS), and a suitable intermediate converter is chosen to connect the DG to DC link of UPQC-DG. Of course, a renewable-based DG is preferred over conventional DG due to environmental benefits. Certain renewable sources such as PV also have cost-benefit over conventional diesel generators. In this work, solar PV is taken as a DG.

Since UPQC-DG is a complex system of three power converters, its control is quite complex. So, it is necessary to develop simplified and efficient control strategies for UPQC-DG. Incorporating DG in control of UPQC-DG is another challenge. Controller should be able to withstand the intermittency of renewable DGs.

Holistic utilization of series and shunt APFs of UPQC-DG is another challenge, and various control strategies based on VA (Volt-Ampere loading) sharing methods have been devised [10–12], but need to be made further efficient and straightforward.

Control techniques of UPQC-DG are required to make robust in the presence of system disturbances such as voltage sag, swell, load change, etc. Dealing with unbalanced source voltages and load currents is especially challenging.

Due to the presence of three converters, the cost of UPQC-DG is high. So, using optimal control techniques, it is desired to reduce VA rating and thus the cost of converters of UPQC-DG, without compromising on its performance.

1.3 Objectives of Proposed Research

Proposed research work has been divided into the following objectives:

1. Development of improved reference generation techniques for control of UPQC-DG by incorporating current generated by Distributed Generator (DG).
2. Design of simple control technique for UPQC-DG to share VA (Volt-Ampere) burden between series and shunt APFs.
3. Development of improved control technique to share VA burden between series and shunt APFs in the presence of unbalanced loads and unbalanced supply voltages.
4. Optimum design of UPQC-DG based on developed VA sharing method.
5. Real-time validation of developed optimal design and improved control techniques of UPQC-DG using Opal-RT.
6. Experimental verification of developed control strategies of UPQC-DG.

1.4 Thesis Organization

The organization of the thesis is as follows:

Chapter-1 describes the background, motivation, and objectives of the research carried out in the thesis.

Chapter-2 describes various existing and state-of-art control techniques of UPQC-DG and identifies research gaps for further improvement.

Chapter-3 covers design aspects of UPQC-DG, such as DC link capacitor calculations, VA sizing of series and shunt APFs and filter design. Design and Matlab simulation of a case study system is presented for various operating conditions of UPQC-DG.

Chapter-4 proposes a simplified power angle control method for UPQC-DG, using the instantaneous power measurement method. Reference signals for control are generated using Synchronous Reference Frame Theory (SRFT) and Unit Vector Template Generation (UVTG). Validation of developed control is done using real-time simulation carried out in OPAL-RT.

Chapter-5 proposes an improved power angle control method of UPQC-DG in the presence of unbalanced loads, and the improvements are quantified in comparison to existing methods. Real-time simulation results are presented to validate developed control.

Chapter-6 proposes a novel optimal design and control method for UPQC-DG based on the modified power angle control method using SRFT. Controller-Hardware-in-Loop (CHIL) results are presented to validate the developed method.

Chapter-7 concludes the thesis outlining its specific contributions and future scope for research.

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