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An improved control method for unified power quality conditioner with unbalanced load

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A R T I C L E I N F O

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A B S T R A C T

This paper proposes an improved control method for Unified Power Quality Conditioner (UPQC) with unbalanced load. In UPQC, shunt APF is overburdened when it alone supplies total load reactive power. PAC method aims at effective utilization of series and shunt APFs by sharing reactive power burden between the two. In presence of unbalanced load, existing PAC methods can lead to circulation of reactive power between two APFs and thereby result in overloading of UPQC. Also, due to unbalanced compensating currents, DC link voltage contains second order oscillations, which deteriorates source current quality. In this work, a new PAC method is proposed, which avoids circulation of reactive power and unnecessary VA burden on UPQC. To suppress DC link voltage oscillations, proposed control employs a 'mean block' (moving average) at output of PI controller, which ensures balanced and harmonic free source currents. Also, a 'percentage unbalance' parameter has been proposed to quantify the unbalance in three phase quantities. Performance of proposed UPQC system is tested in the presence of non-linear, reactive and unbalanced loads. Dynamic performance of system is studied during grid disturbances such as voltage sag, swell, and change in load. Real time simulation carried out in Opal-RT validate the effectiveness of proposed method. The electrical circuit of UPQC is simulated with sub-microsecond time step on FPGA based computational engine of Opal-RT for better verification of the proposed control.

1. Introduction

Power quality is one of the major challenges of smart grid [1]. With increasing use of power electronic converters, power quality issues such as harmonic distortions have been increasing rapidly. Active Power Filters (APFs) being dynamic and fast, are preferred over passive filters to compensate for power quality issues. Series APF mainly compensates for supply voltage related power quality problems such as voltage sag, swell and harmonics. On other hand, shunt APF mainly compensates for load current related power quality issues such as poor power factor, unbalance, and harmonics. UPQC (Unified Power Quality Conditioner) is a combination of series and shunt APFs sharing a common DC link. UPQC, integrating benefits of both series and shunt APF, compensates for most of the power quality issues [2].

Shunt APF of UPQC identifies non-linear and out of phase components from load currents and supplies them to load, maintaining balanced, sinusoidal source currents with unity power factor. To achieve this function, many techniques such as Instantaneous Reactive Power Theory (IRPT or p-q theory), Synchronous Reference Frame Theory (SRFT or d-q theory) are used. IRPT based techniques for shunt APF are simple and have been used widely [3,4]. However, IRPT based techniques don't perform well in non-ideal supply voltage conditions, so SRFT based techniques are preferred over IRPT based techniques [5,6]. Apart from comensating for load current based power quality issues, shunt APF also regulates DC link voltage, for which a PI controller is used generally.

Series APF of UPQC monitors supply voltage and detects any non-ideality such as sag, swell or harmonics. These non-ideal components of supply voltages are extracted by series APF and corresponding compensating voltages are injected in series with supply voltages to maintain ideal voltage across load terminals. To accomplish this task, various control techniques are used in literature such as IRPT [1], SRFT [5,7], and Unit Vector Template Generation (UVTG) [8]. UVTG based technique is simple and doesn't require any PI controller [8]. In absence of non-ideality in supply voltage, output voltages of series APF are effectively zero.

VA rating of series APF is under-utilized if it compensates only for transient grid disturbances such as voltage sag and swell, so Power Angle Control (PAC), which aims at effective utilization of VA ratings of series and shunt APF of UPQC, has been proposed [3,9]. In PAC, series APF provides part of load reactive power by injecting voltage at an angle with source current (unlike conventional control, in which series

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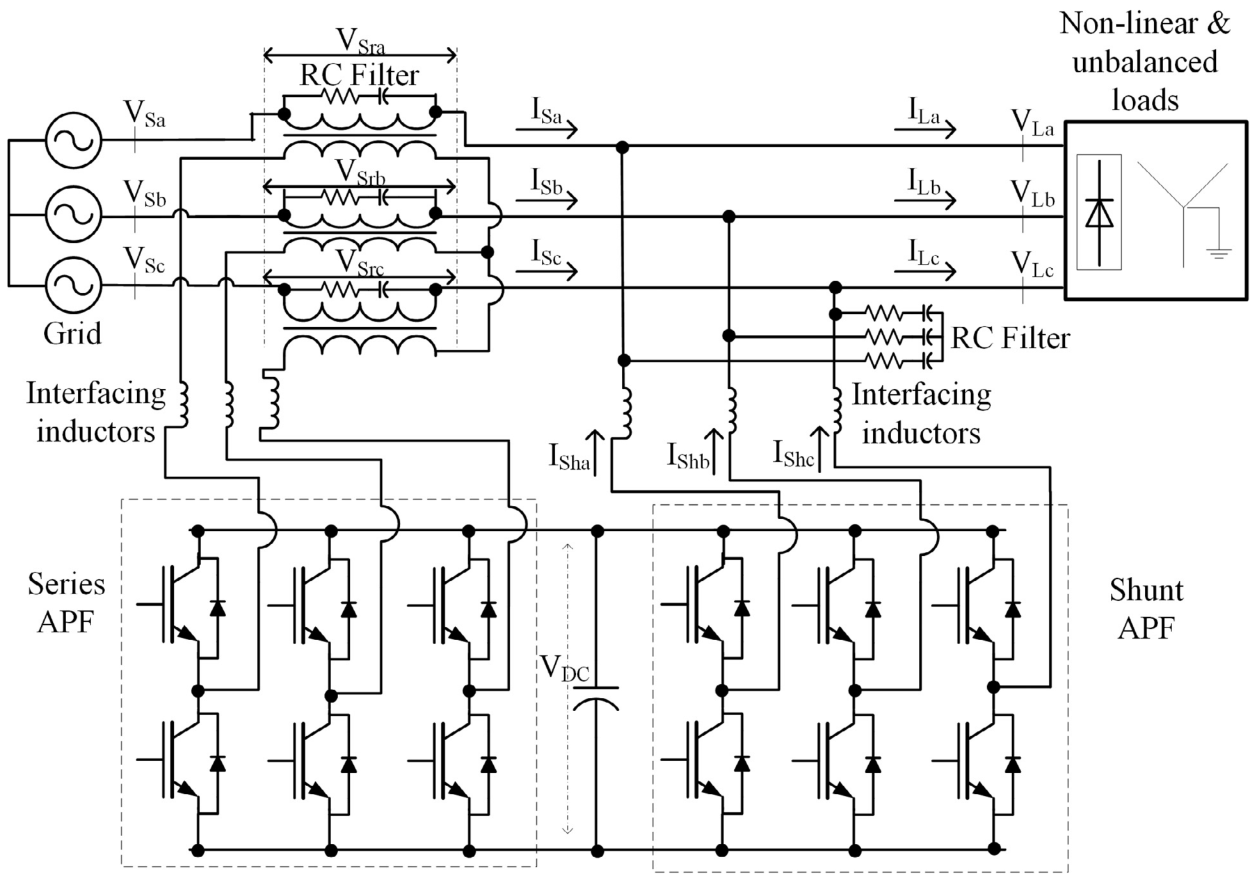

Fig. 1. Configuration of 3-phase, 3-wire UPQC.

APF injects voltage in phase with source current). Out of phase injection of series voltage introduces a phase angle, commonly known as power angle, between load voltage and source voltage. During voltage sag or swell, series APF in PAC approach compensates for sag or swell along with providing part of load reactive power either by keeping power angle constant or varying it suitably [4].

In short, control of UPQC involves measurement of source and load voltages and currents, computation of PAC algorithms, on-line generation of reference currents for shunt APF & reference voltages for series APF, and feedback control in these APFs. However, overall performance of UPQC depends on regulation of DC link voltage [10]. In presence of unbalanced loads, shunt APF supplies unbalanced components of load currents, due to which DC link voltage experiences second order oscillations, which eventually affect the performance of UPQC.

Good amount of research has been already carried out on control and performance of UPQC in presence of unbalanced loads [5,11,12], however, little attention is given to DC link voltage oscillations, its effects on performance of UPQC, and solution for it. A sinusoidal integration block is added to remove DC link voltage oscillations in shunt APF with unbalanced load [13], and a proportional resonant controller is used in place of conventional PI controller [14], but these methods are complex, increase computation burden on controller, and have slow dynamic response.

Most of the PAC methods proposed for UPQC, don't account for inherent system non-idealties like distortion is source voltage and unbalance in loads. PAC method of UPQC in works [3,4] is based on IRPT theory (p-q theory), which makes this method sensitive to non-ideal supply voltages. So, SRFT (d-q theory) based PAC method for UPQC has been developed, but sag/swell compensation along with PAC is not considered in control of series APF [15].

SRFT based PAC method, which shares load reactive power equally between series and shunt APF has been developed to achieve equal VA loading of these APFs [16], but method is complex and gives accurate results only with very small values of power angle because load power is calculated in source voltage reference frame, which differs considerably from load voltage reference frame for appreciable value of power angle. PAC methods proposed so far, don't consider DC link voltage oscillations in presence of non-linear loads. Apart from this, in existing PAC methods, unbalanced load can cause circulation of reactive power, which leads to increase in power losses and overloading of UPQC (which is proven theoretically as well as by real time simulation in present work).

In the present work, following improvements are proposed in UPQC control:

- A new PAC method is proposed to avoid circulation of reactive power and associated overloading of UPQC in presence of unbalanced load.
- To minimize effects of DC link voltage oscillations, a 'mean' (moving average) block is added at the output of PI controller. The 'mean' block removes oscillations in current estimated by PI controller, which results in improvement in source current power quality.

Performance of proposed system is tested in steady state as well as in dynamic states using real time digital simulation with help of Opal-RT.

The rest of paper is organized as follows: Section 2 describes configuration of solar PV based UPQC. Section 3 gives mathematical analysis of PAC method of UPQC. Section 4 covers control of UPQC with proposed PAC approach. Section 5 presents simulation test case with methodology, Section 6 discusses results and Section 7 concludes contribution of the paper.