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Resistive optimization with enhanced PLL based nonlinear variable gain fuzzy hysteresis control strategy for unified power quality conditioner

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A B S T R A C T

This paper proposes a Resistive Optimization Technique (ROT) incorporated with enhanced phase-locked loop (EPLL) based Nonlinear Variable Gain Fuzzy (NVGF) hysteresis control strategy for three-phase, three-wire Unified Power Quality Conditioner (UPQC) for compensating current harmonics, reactive power, voltage sag/swell, voltage harmonics and voltage unbalance present in the power system distribution network. This novel resistive optimization control strategy is exploited for reference signal generation for both shunt and series inverter. This proposed algorithm adaptively regulates the DC-link capacitor voltage without utilizing additional controller circuit and makes the control system simple as it does not involve any complex optimization methods. Furthermore, a nonlinear variable gain fuzzy based hysteresis controller is proposed for controlling the hysteresis band, which effectively reduces the band violation and improves the tracking behavior of UPQC during load transient, distortion and unbalanced supply conditions of power system. The proposed control strategy of UPQC is validated through MATLAB/SIMULINK followed by the experimental setup accomplished with real-time-hardware-in the loop (HIL) system OPAL-RT simulator and adequate results are reported after a comparative assessment with the conventional PI and hysteresis controller.

Introduction

Over recent years, there has been a significant increase in the installation and usage of nonlinear equipment such as adjustable-speed drives, fluorescent lighting, induction heating, static power converters and power supplies for computer and sophisticated equipment utilized in industries and for household purpose. These devices produce power quality (PQ) problems by generating or amplifying existing current-harmonics [1] that cause overheating of electrical equipment and distorting the voltage waveform. Various network faults and lightning can also produce PQ problems such as voltage unbalance and sag/swell. These voltage instabilities can create malfunction in sensitive loads [2] such as computer and microprocessor based equipment used in our home, office, hospital and industries. Thus, a modern distribution system demands a better stability of voltage being supplied and the current drawn, which is an essential perspective to the end user.

Under these circumstances, UPQC is one of the best solutions for eliminating PQ problem in the power distribution line. UPQC is a custom power device where shunt inverter and series inverter are integrated together through a common DC-link capacitor [3]. The shunt inverter is connected in parallel with load to overcome the current related problems, whereas series inverter is connected in series with line to tackle voltage related problems [4]. UPQC has recently gained attention of power engineers to improve dynamic solution of PQ issues, which demands in the development of advanced control strategy. Fast and accurate extraction of reference signal, as well as fast regulation of DC-link voltage during transient and voltage disturbance condition are the primary requirements of any control strategy.

The control strategy of UPQC consists of two major aspects: one is based on the extraction of reference signals and another the generation of pulse-width-modulation (PWM) signal. The control techniques for extraction of reference signals reported in literature include instantaneous power theory, rotating reference frame, neural-network and output regulation with Kalman filter [5–7]. All these aforementioned techniques have considered more than half cycle to estimate change in amplitude of load current at the beginning [8]. Hence, the compensation speed of the UPQC decreases significantly, which leads to increased oscillations in DC-link voltage. Furthermore, a low-pass filter (LPF) [9] is used for filtering the ripples present in the dc-link voltage, which introduces a finite delay resulting in large settling time of dc-link voltage. Additionally, utilization of fixed dc-link voltage control

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techniques can generate switching losses and conduction losses with the variation of load as well as supply voltage [10]. Therefore, dc-link voltage has to be changed adaptively with load and supply side perturbations, which can result in better compensation performance and operational flexibility as compared to the conventional fixed dc-link voltage PI-controller [11]. With above-mentioned views, the proposed control technique utilizes enhanced phase-locked-loop (EPLL) technique for perfect extraction of positive sequence signal during power system perturbation and computes optimum value of resistance for generation of the reference signal with self-supporting dc-link voltage. The proposed control technique provides fast detection of transient conditions occurred in the supply or load sides, and accordingly dc-link voltage is regulated by changing the amplitude of the real fundamental component of the reference current. Therefore, a small amount of real power is flowing through the shunt inverter into the dc-link capacitor for compensating conduction and switching losses and keeps the dc-link voltage constant.

On the other hand, to accomplish significant compensation with good accuracy and very fast response, hysteresis controllers [12] are well known for PWM signal generation. However, the conventional hysteresis technique exhibits an undesirable feature such as variable switching frequency. As a result, the switching losses are increased, and the source current, as well as the load voltage contain some additional ripples. Several papers are reported in the literature that deal with these issues and try to eliminate such drawbacks by many effective solutions [13–15], which are based on controlling the hysteresis bandwidth. The adaptive hysteresis band controller (AHBC) [16–18] provides excellent performance by reducing the switching losses, but fails to provide satisfactory performance during dynamic as well as uncertainty condition of load and supply voltage variation. To eliminate this drawback, a NVGF [19,20] based hysteresis controller is considered for PWM signal generation in both shunt and series inverter of UPQC. This hysteresis controller provides a better hysteresis band computation approach during power system dynamic and transient condition.

Under these circumstances mamdani fuzzy logic controller is unable to provide a wide variation of control gain for controlling the hysteresis band during a load transient, sag/swell, voltage unbalance and distorted source voltage condition. This results in band violation and tracking performance degradation. This problem can be eliminated by NVGF hysteresis controller based on Takagi–Sugeno (TS) fuzzy rule scheme, where an extensive variation of the controller gain improves the tracking performance to a large extent. The performance of the proposed approach is validated through MATLAB/SIMULINK followed by the real-time experimental studies, which are accomplished by using hardware-in-the-loop (HIL) system OPAL-RT simulator (OP5600) with Xilinx SPARTAN-3(3xc3s5000) OP5142 field programmable gate array (FPGA) processor for user interconnection. A comparative analysis has been performed between proposed control strategy and conventional PI-controller for dc-link voltage regulation. Also current and voltage tracking performance of UPQC have been compared with fixed as well as adaptive hysteresis controller.

Structure of UPQC

Fig. 1 shows the structure of a UPQC, which is integration of two voltage source inverter (VSI), connected back to back through a common dc-link bus [21]. One VSI is connected in parallel with load which performs as a shunt compensator and another one is connected in series with the line that works as series compensator. The shunt inverter has the best capability for tackling current related problems; however the series inverter is most appropriate for voltage-related problems. A three phase uncontrolled diode-bridge rectifier with resistive R_L and inductive L_L load is used as a nonlinear load for producing current harmonics. Shunt interfacing inductor (L_{sh}) is utilized for coupling the shunt compensator to the system network and a *LC* filter serves as a passive low-pass filter (LPF) to remove the high frequency switching ripples present in the series compensator output voltage. The series transformer connected in series with the power line is utilized to establish a link between the series inverter and the system network.

Proposed resistive optimization technique

Distorted, unbalanced and faulty supply conditions create numerous problems in power system. In such situations, extraction of reference signal is one of the challenging tasks, as compensation capability of UPQC depends on how accurately and how quickly the reference signals are extracted from power system. To overcome such issues, a novel control structure is proposed to calculate the optimal value of resistance for generating the reference signal and regulating the dc-link voltage to eradicate the PQ problems present in power system. Additionally, the quality of grid synchronization is a significant factor which determines the complete control structure compensation capability of PQ problems; therefore an Enhanced phase locked loop (EPLL) is employed for

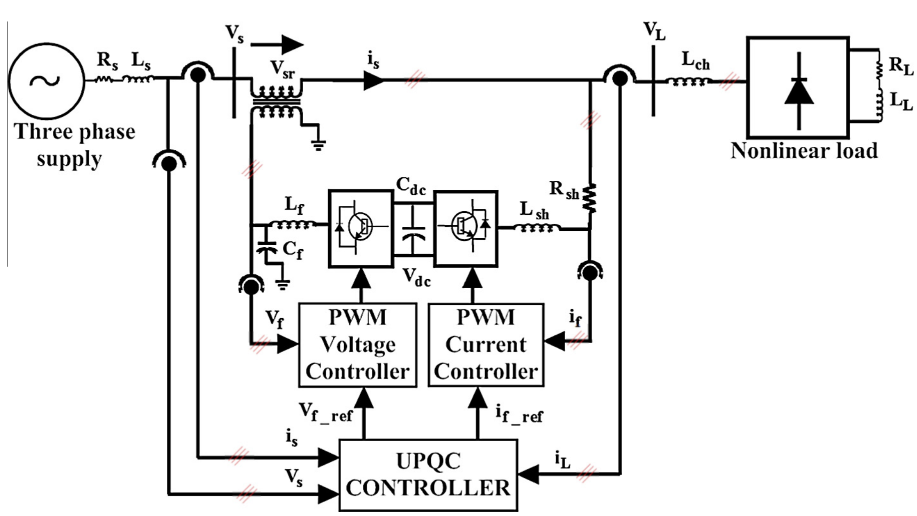

Fig. 1. Structure of UPQC.