Reduced Rating VSC With a Zig-Zag Transformer for Current Compensation in a Three-Phase Four-Wire Distribution System

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***Abstract*—A detailed investigation is made into the causes, standards, and remedies of the excessive neutral current. A reduced-rating voltage-source converter with a zig-zag transformer as a distribution static compensator is proposed for power-quality improvement in the three-phase four-wire distribution system. The proposed DSTATCOM is employed for the compensation of reactive power, harmonics currents, neutral current, load balancing and the voltage regulation at the point of common coupling. The zig-zag transformer is used for providing a path to the zero-sequence current. The performance of the DSTATCOM is validated through extensive simulations using MATLAB software with its Simulink and power system blockset toolboxes.**

***Index Terms*—Distribution static compensator (DSTATCOM), neutral current compensation, power quality (PQ), zig-zag transformer.**

I. Introduction

Distribution systems are facing severe power-quality (PQ) problems, such as poor voltage regulation, high reactive power and harmonics current burden, load unbalancing, excessive neutral current, etc. The source voltages in the distribution systems are also experiencing PQ problems, such as harmonics, unbalance, flicker, sag, swell, etc. [1]–[11]. In order to limit the PQ problems, many standards are also proposed, such as IEEE 519-1992, IEEE Std. 141- 1993, IEC 1000-3-2, etc. [12]–[18]. The remedial solutions to the PQ problems are investigated and discussed in the literature [4]–[11] and the group of devices is known as custom power devices (CPDs). The distribution static compensator (DSTATCOM) is proposed for compensating PQ problems in the current, and the dynamic voltage restorer (DVR) is used for mitigating the PQ problems in the voltage while the unified power-quality conditioner (UPQC) is proposed for solving current and voltage PQ problems. There are many techniques reported for the elimination of harmonics from the source current as well as the compensation of the neutral current and load balancing [19]–[23]. Some neutral current compensation techniques have been patented [24]–[27].

Three-phase four wire distribution systems have been used to supply single-phase low-voltage loads. The typical loads may be computer loads, office automation machines, lighting ballasts, adjustable speeds drives (ASDs) in small air conditioners, fans, refrigerators, and other domestic and commercial appliances, etc., and generally behave as nonlinear loads. These loads may create problems of high input current harmonics and excessive neutral current. The neutral current consists of mainly triplen harmonics currents. The zero-sequence neutral current obtains a path through the neutral conductor. Moreover, the unbalanced single-phase loads also result in serious zero-sequence fundamental current. The total neutral current is the sum of the zero-sequence harmonic component and the zero-sequence fundamental component of the unbalanced load current, and this may overload the neutral conductor of the three-phase four-wire distribution system.

A number of surveys have been cited about the causes of excessive neutral current in the distribution system [31]–[35]. There are different techniques for the mitigation of neutral current in the three-phase four-wire distribution systems [35]–[54]. The neutral current compensation using a zig-zag transformer [35]–[38]; using a star/delta transformer [39], [40]; using a single-phase active compensator in the neutral path [41]–[43]; and using three-phase four-wire active compensators along with source harmonic current compensation [44]–[54] are reported in the literature. In this investigation, the causes, standards, and remedial solutions for PQ problems due to the excessive neutral current are analyzed and a technique using a zig-zag transformer along with a reduced rating VSC as a DSTATCOM is designed to mitigate these PQ problems. Moreover, the voltage regulation is also achieved at the point of common coupling (PCC) across the loads.

II. Neutral Current Compensation Techniques

The major causes of neutral current in three-phase distribution systems are the phase current unbalance, third harmonic currents produced by single-phase rectifier loads, and the third harmonics due to source voltage third harmonics [28]. Even balanced three-phase currents produce excessive neutral current with computer loads in the systems. A study reveals that 22.6% of the sites have a neutral current in excess of 100% [29]–[31]. The source voltage distortions in systems with computer loads

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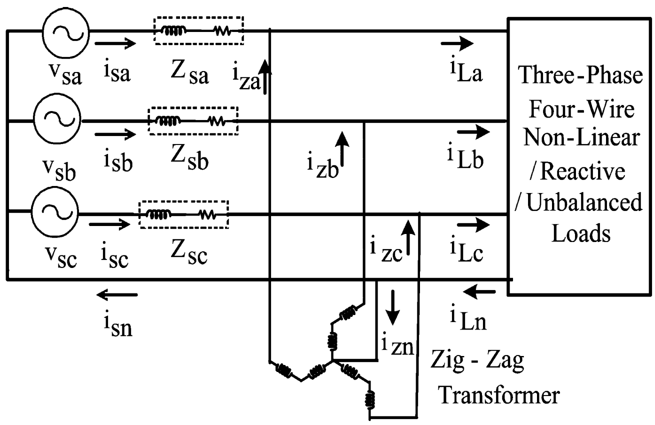

Fig. 1. System configuration with a zig-zag transformer for neutral current compensation.

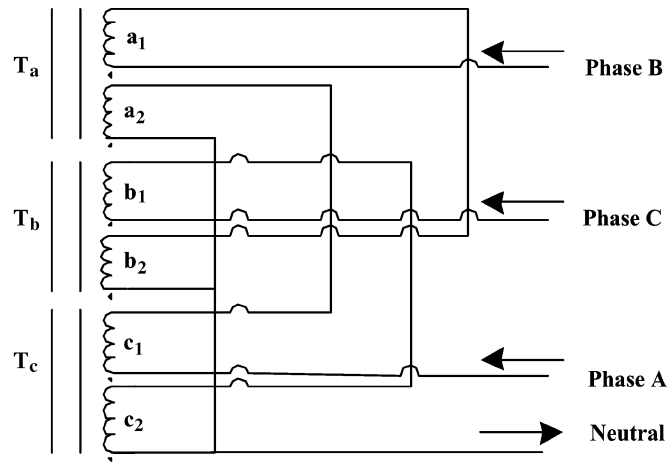

Fig. 2. Zig-zag transformer for neutral current compensation.

can cause excessive neutral current [32], [33]. The nonlinear loads are classified into harmonic current source loads and harmonic voltage-source loads [34].

Various standards are proposed to mitigate PQ problems in the distribution system [12]–[18]. The planning for a distribution system, the voltage considerations, calculation of short-circuit capacities, power factor improvement techniques, protective devices, surge protection, and grounding aspects are proposed in IEEE Standard 141-1993 [12]. It is a complete guide for an industrial plant power system. The recommended practice for electrical power systems in commercial buildings [13], the recommendation for harmonic control in power systems [14], the reference on shunt capacitor design, installation guidelines of improvement of power factor and other applications [15], the practices for monitoring electrical PQ [16], and the guide for the application and specification of harmonic filters [17] are available in the literature. In light of the various standards, there are many techniques proposed for the compensation of neutral current in the three-phase four-wire distribution system. These are discussed in the following sections.

A. Zig-Zag Transformer-Based Compensation

The application of a zig-zag transformer for the reduction of neutral current is advantageous due to passive compensation, rugged, and less complex over the active compensation techniques [35], [37]. Fig. 1 shows the connection of a zig-zag transformer in the system and the zig-zag transformer is shown in Fig. 2. A zig-zag transformer is a special connection of three single-phase transformer windings or a three-phase transformer's windings. The zig-zag transformer in the past has been used to create neutral and to convert a three-phase three-wire system into a three-phase four-wire system. The new application of a zig-zag transformer is to connect in parallel to the load for filtering the zero-sequence components of the load currents. The phasor diagram of the zig-zag transformer is shown in Fig. 3. The currents flowing through the utility side of these three transformers are equal. Hence, the zig-zag transformer can be regarded as open-circuit for the positive-sequence and the negative-sequence currents. Then, the current flowing through the zig-zag transformer is only the zero-sequence component.

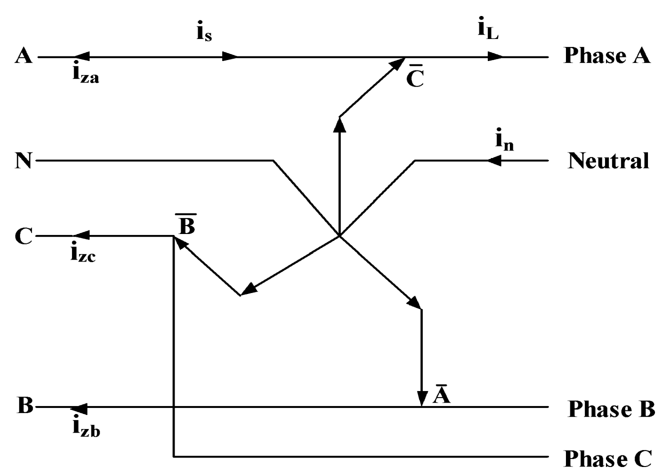

Fig. 3. Diagram showing the flow of currents of zig-zag transformer for neutral current compensation.

An application of a zig-zag transformer alone in a three-phase, four-wire system has the advantages of reduction in load unbalance and reducing the neutral current on the source side. But there are inherent disadvantages such as the performance being dependent on the location of the zig-zag transformer close to the load. Moreover, when the source voltage is distorted or unbalanced, the performance of reducing the neutral current on the source side is affected to an extent.

B. Zig-Zag Transformer With Active Filter-Based Compensation

A hybrid filter consisting of a single-phase VSC and a zig-zag transformer is also efficient in neutral current compensation [36], [38] and the topology is shown in Fig. 4. A different topology for a single-phase VSC with a self-supporting dc bus and zig-zag transformer-based neutral current compensation system [37] is shown in Fig. 5.

C. Star/Delta Transformer-Based Compensation

A star-delta transformer and an active filter are used for harmonic current reduction in the neutral conductor [26]. A filter is