

Current Compensation with Reduced Rating VSC and A ZIG – ZAG Transformer an A Three Phase Four-Wire Distribution System

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ABSTRACT—

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 source voltages in the distribution systems are also experiencing power quality problems, such as harmonics, unbalance, flicker, sag, swell, etc. The distribution static compensator (DSTATCOM) is proposed for compensating power quality problems in the current, and the dynamic voltage restorer (DVR) is used for mitigating the power quality problems in the voltage. The zig-zag transformer is used for the neutral current compensation.

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 zig-zag transformer is used for providing a path to the zero-sequence current. The DSTATCOM is used to improve the quality of power to the non linear loads. By using both zig-zag transformer and DSTATCOM in the distribution system the rating of the voltage source converter can be reduced. Hence it can be also called reduced rating device.

The performance of the DSTATCOM is validated through extensive simulations using MATLAB software with its Simulink and power system block set 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. In order to limit the PQ problems, many standards are also proposed.

The remedial solutions to the PQ problems are investigated and discussed in the literature 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).

It 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. Some neutral current compensation techniques have been patented. 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. There are different techniques for the mitigation of neutral current in the three-phase four-wire distribution systems. The neutral current compensation using a zig-zag transformer; using a

star/delta transformer; using a single-phase active compensator in the neutral path; and using three-phase four-wire active compensators along with source harmonic current compensation 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. 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%. The source voltage distortions in systems with computer loads can cause excessive neutral current. The nonlinear loads are classified into harmonic current source loads and harmonic voltage-source loads. Various standards are proposed to mitigate PQ problems in the distribution system. 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. It is a complete guide for an industrial plant power system. The recommended practice for electrical power systems in commercial buildings, the recommendation for harmonic control in power systems, the reference on shunt capacitor design, installation guidelines of improvement of power factor and other applications, the practices for monitoring electrical PQ, and the guide for the application and specification of harmonic filters 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. 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.

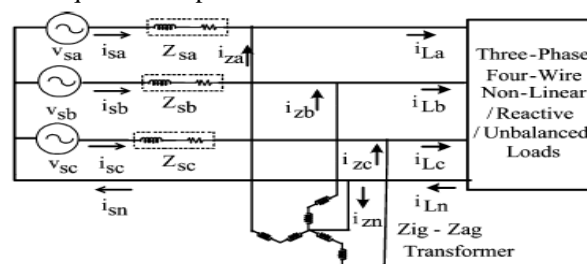


Fig.1. System configuration with a zig-zag transformer for neutral current Compensation

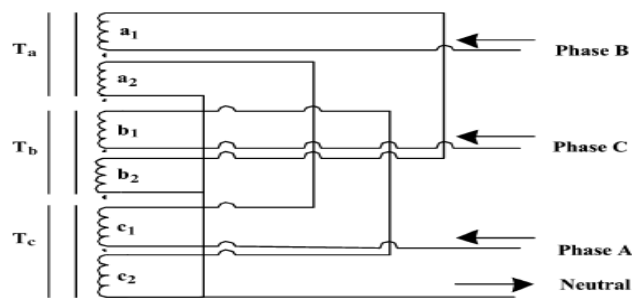


Fig.2. Zig-zag transformer for neutral current compensation

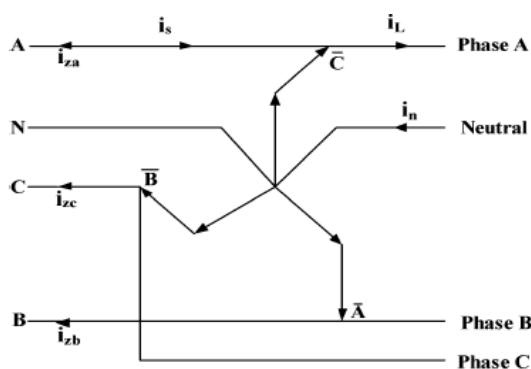


Fig.3. Diagram showing the flow of currents of zig-zag transformer for neutral current compensation

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 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 is shown in Fig. 5.

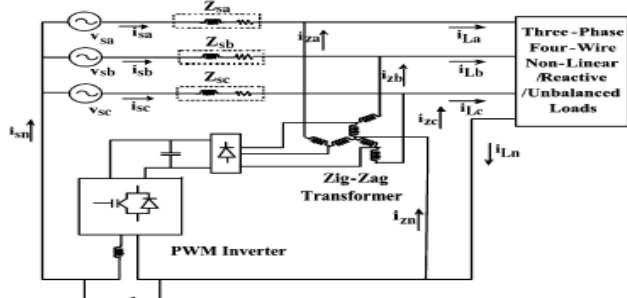


Fig.4.Reduced rating single-phase inverter with a zig-zag transformer for neutral current compensation.

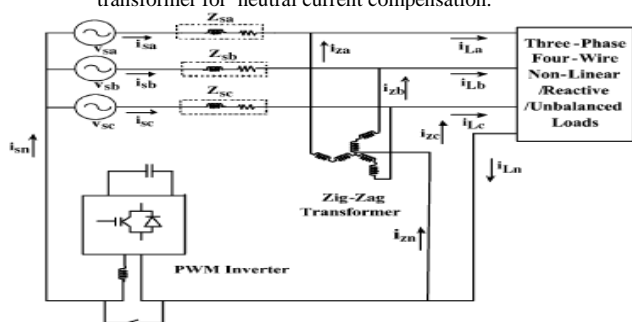


Fig. 5. Hybrid neutral current compensator using a single-phase inverter and zig-zag transformer.

C. Star/Delta Transformer-Based Compensation

A star-delta transformer and an active filter are used for harmonic current reduction in the neutral conductor. A filter is used for removing harmonic current from the neutral conductor employing three single-phase transformers with a capacitor, and it has been patented. A scheme using two transformers connected in anti phase, providing a six-phase system, cancels third harmonic currents along a common neutral conductor. Fig. 6 shows the star-delta transformer connection for compensating the neutral current. It consists of a star-delta transformer, a diode rectifier, and a half-bridge PWM inverter. The active power filter generates compensating currents that result in effective cancellation of harmonic currents flowing in the neutral conductor. The advantage of such a scheme is that it does not require a special designed transformer and its effectiveness does not depend on the location of installation.

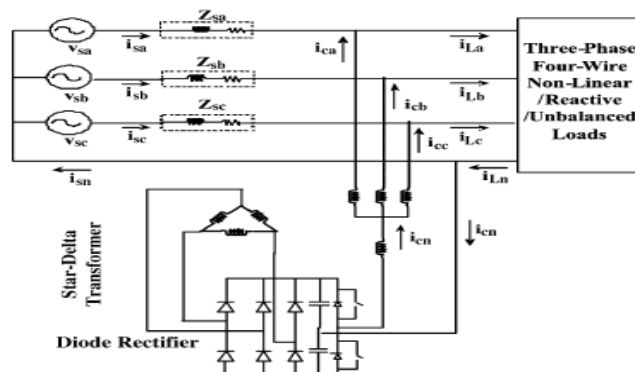


Fig.6. Star-delta transformer-based neutral current compensator

D. Three-Phase Four-Wire Active Compensators

The neutral current along with harmonics, reactive power compensation, and load balancing are achieved using three phase four-wire DSTATCOM-based compensators. Three different topologies for three-phase four-wire DSTATCOMs, such as a voltage-source converter (VSC), with four leg, three single-phase VSC, and three-leg VSC with split capacitors are reported in the literature. Fig. 7 shows a four-leg DSTATCOM, split capacitor-based three-leg DSTATCOM is shown in Fig. 8, and Fig. 9 shows three single-phase VSC-based DSTATCOMs. Some researchers select the four-leg converter topology as the best alternative compared to others considering the number of switching devices, complexity of control, etc.

There are different control techniques reported for deriving the reference control signals for the DSTATCOM. The instantaneous reactive power theory ($-$ theory), synchronous reference frame (SRF) theory or $-$ theory, power balance theory, etc., have been proposed to control the DSTATCOM for three-phase four-wire systems. The control of the three-phase four-wire compensation under non sinusoidal source conditions is verified to be satisfactory in and the method is based on $-$ theory. The instantaneous active and reactive powers are calculated after filtering out the harmonics in voltage and the theory is evaluated for a three-phase four-wire four-leg VSC-based system. The three-phase four-wire DSTATCOM-based systems are reported as very effective for the compensation, including neutral current. But this configuration has the disadvantages of a greater number of semiconductor switches, complexity of control, etc. A three-phase three-leg shunt compensator and a zig-zag transformer for neutral current compensation are shown in Fig. 10.

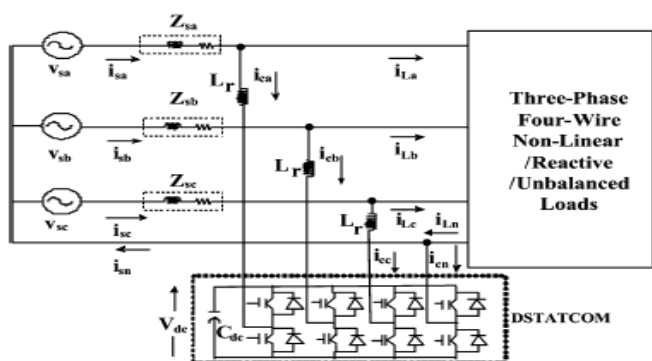


Fig.7. Three-phase four-leg DSTATCOM for neutral current compensation

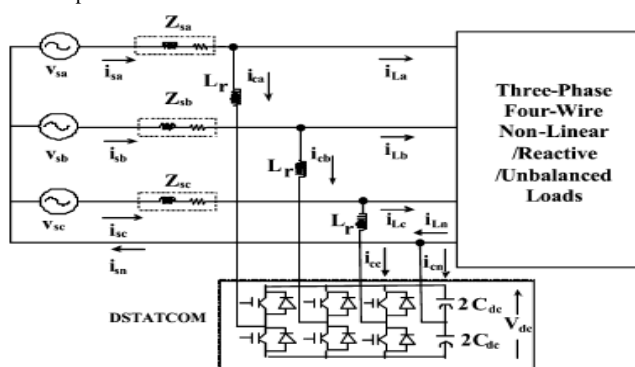


Fig.8. Three-phase three-leg and split capacitor-based STATCOM for neutral current compensation

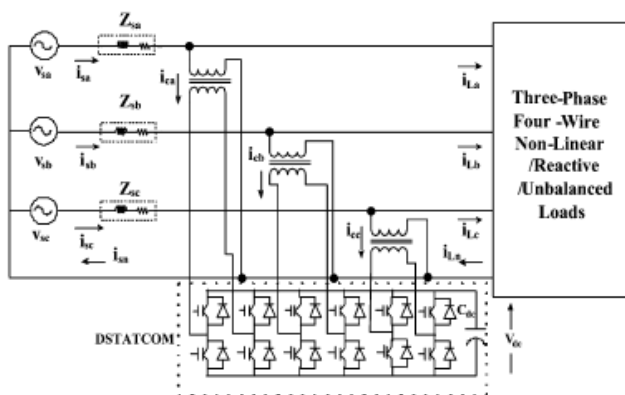


Fig.9. Three single-phase VSC-based DSTATCOM for neutral current compensation

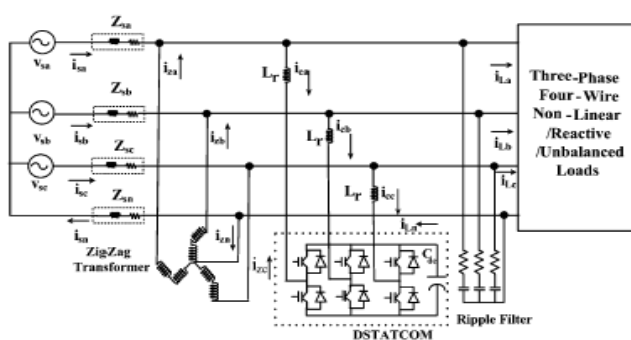


Fig.10. Three-leg VSC-based DSTATCOM and zig-zag transformer for neutral current compensation

III. RESULTS AND DISCUSSION

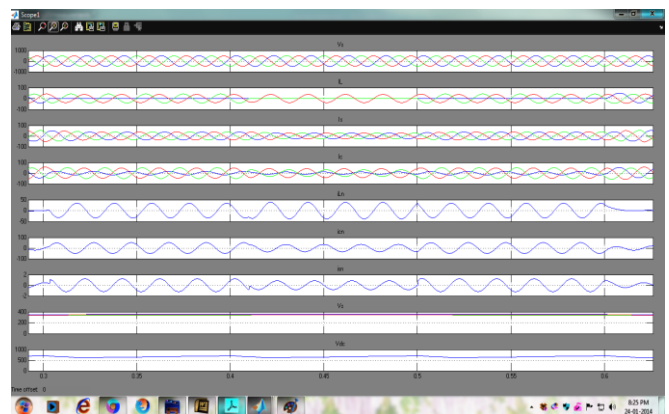
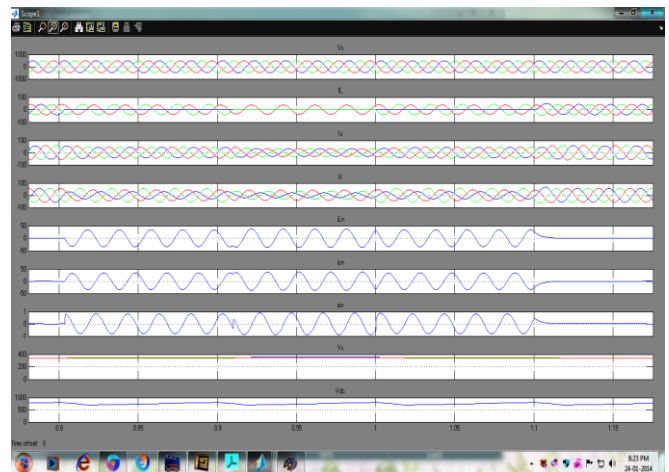
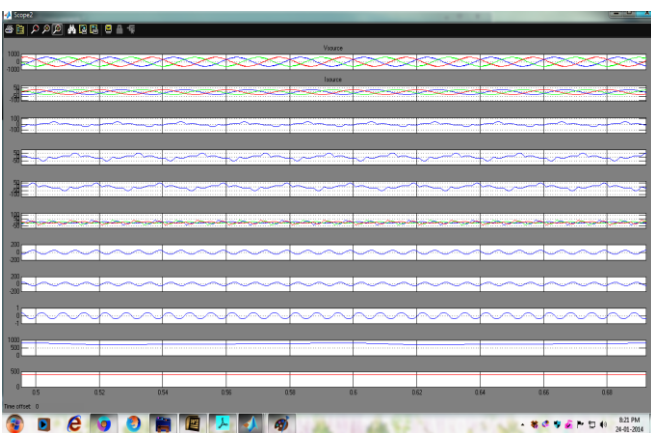
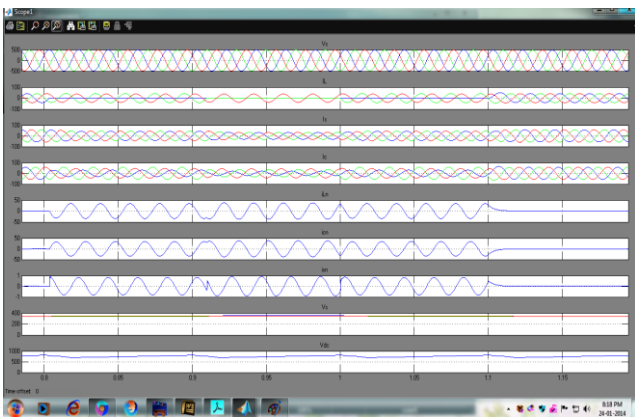
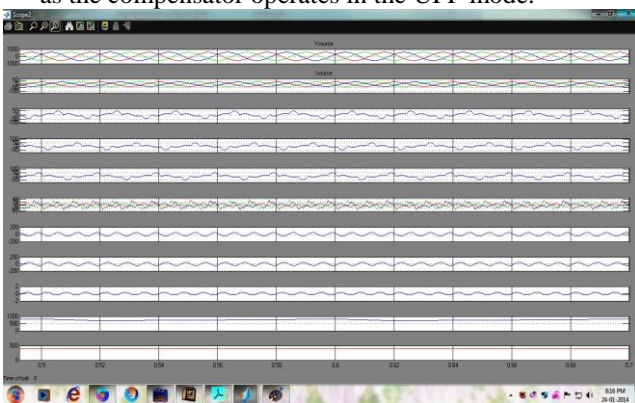
Some of the important neutral current mitigation techniques are analyzed and modeled using MATLAB. The performance of harmonic neutral current compensation using the zig-zag transformer for the nonlinear load and linear load are shown in Figs. 13 and 14, respectively. The voltages, source currents, load currents, zig-zag transformer currents, load neutral current, source neutral current, and zig-zag transformer neutral source neutral current and zig-zag neutral current are demonstrated. It is observed that the zig-zag transformer has compensated the load neutral current, resulting in a source neutral current of nearly zero.

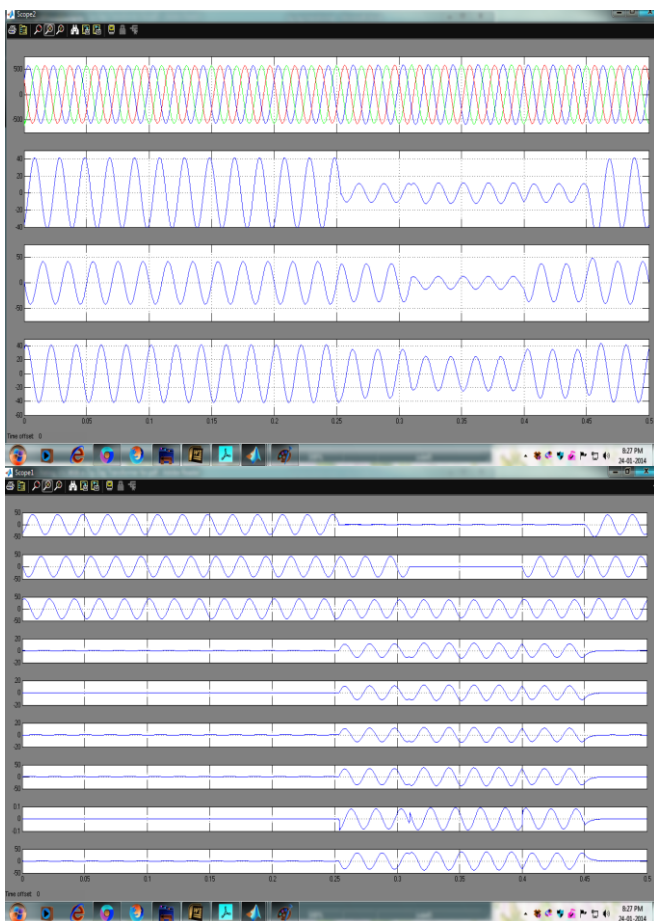
The performance using a three-phase four-leg DSTATOM for voltage regulation along with neutral current compensation and load balancing of a three-phase four-wire load is shown in Fig. 15. The voltages, balanced source currents, load currents, compensator currents, load neutral current, compensator neutral current, source neutral current, amplitude of the load terminal voltage, and dc bus voltage are demonstrated under changing load conditions. It is observed that the amplitude of the load voltage is regulated to the reference amplitude by the required reactive power compensation. The performance of voltage regulation, along with neutral current compensation and load balancing of a three-phase four wire load using the proposed three-phase three-leg VSC and a zig-zag transformer as DSTATCOM, is depicted in Fig. 16. The voltages, balanced source currents, load currents, compensator currents, source neutral current, load neutral current, compensator neutral current, amplitude of the load terminal voltage, and dc bus voltage are demonstrated under changing load conditions. It is observed that the voltage amplitude is regulated to the reference value under all load disturbances. The source current is balanced, even though the load current is highly unbalanced and this is achieved by using the unbalanced fundamental current injection by the DSTATCOM. The zero-sequence fundamental current of the load neutral current resulting from the unbalanced load current is circulated in the zig-zag transformer, and hence, the source neutral current is maintained at nearly zero. The dc bus voltage of the VSC of DSTATCOM is regulated by the controller and the voltage is maintained near the reference voltage under all load disturbances.

The performance of the DSTATCOM with a zig-zag transformer for voltage regulation and harmonic elimination along with neutral current compensation is shown in Fig. 17. The voltages, source currents, load currents, compensator currents, load neutral current, zig-zag transformer neutral current, source neutral current, dc bus voltage, and amplitude of the load terminal voltage are demonstrated under various

nonlinear loads. It is observed that the terminal voltage is regulated to the reference value.

The dynamic performances of the DSTATCOM system in the unity power factor (UPF) mode of operation are depicted in Figs. 18 and 19. The load balancing and neutral current compensation are demonstrated in Fig. 18 and the harmonic elimination and neutral current compensation are demonstrated in Fig. 19. The voltages, source currents, load currents, compensator currents, source neutral current, load neutral current, zig-zag transformer neutral current, amplitude of load terminal voltage, and dc bus voltage are shown in both cases. It is also observed that the terminal voltage is not regulated in both cases as the compensator operates in the UPF mode.





IV. CONCLUSION

The causes, standards, and mitigation techniques of the excessive neutral current have been investigated in the three-phase four-wire distribution system. The modeling and simulation of the zig-zag transformer has been demonstrated for neutral current compensation. Moreover, a hybrid of zig-zag transformer with a three-phase three-leg DSTATCOM has been observed as an effective option for overall compensation. The performance of the proposed compensator is validated through extensive computer simulation.

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