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Advanced Topology for Nonlinear Loads and Compensation of Reactive Power

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***Abstract*— A higher rating for voltage source converters is necessary due to shunt compensation for medium voltage distribution systems (VSCs). Because the ratings of the semiconductor devices in a VSC are always finite, it is preferable for higher rated converters to use multilayer architecture to spread the stress across a larger number of devices. In comparison to the setups of the diode-clamped and flying capacitor multilevel inverters, the cascaded multilevel inverter has the advantages of simplicity and versatility. The use of cascaded multilevel converters for distribution system shunt correction has been documented in the literature. In order to compensate for reactive power and harmonics, this research examines the use of a five-level cascaded H-bridge (CHB) inverter as a distribution static compensator (DSTATCOM) in the power system (PS). Low harmonic distortion, fewer switches, and the elimination of switching losses are benefits of the CHB inverter. For shunt correction of an 11 kV distribution system, a CHB inverter is taken into consideration. In order to study the performance of the CHB Inverter, level shift carrier PWM (LSCPWM) and phase shifted PWM (PSPWM) techniques are finally used. The software suite Matlab/Simulink is used to produce the results. Both linear and nonlinear loads are simulated for the proposed DSTATCOM.**

Keywords--- DSTATCOM, Power Quality Level Shifted Pulse width Modulation, Phase Shifted Pulse width Modulation (PSPWM), Proportional-Integral Control.

I. INTRODUCTION

In order to fulfil the rising demand for electricity, the size and complexity of the electric power system have increased along with the number of interconnections. Additionally, the need of long-distance and massive electricity transmission lines increases.

Power quality requirements are becoming increasingly crucial today to maintain electrical device safety and customer satisfaction. In recent years, the concept of electric power quality has drawn more and more attention in the field of power engineering. Even while power engineers have always been interested in this topic, the 1990s saw a significant increase in interest. For various people, the quality of the electricity signifies different things. Most electric power engineers understand the phrase to mean a specific, sufficiently high grade of electric service, but there is no consensus beyond that. Power quality requirements are becoming increasingly crucial today to maintain electrical device safety and customer satisfaction. In recent years, the concept of electric power quality has drawn more and more attention in the field of power engineering. Even while power engineers have always been interested in this topic, the 1990s saw a significant increase in interest. For various people, the quality of the electricity signifies different things. Most electric power engineers understand the phrase to mean a specific, sufficiently high grade of electric service, but there is no consensus beyond that.

Thousands of load centres and hundreds of producing stations are connected by extensive power transmission and distribution networks to form the complex networks that make up modern power systems. Although the generation of power is generally reliable, the quality of the power is not always. Customers of a power distribution system should receive an unbroken supply of energy at a smooth sinusoidal voltage at the agreed-upon magnitude level and frequency.

Numerous non-linear loads, particularly in distribution systems, in PS have a substantial impact on power quality. Power quality (PQ) issues can also be caused by non-linear loads, unexpected errors, motor starting, and capacitor switching. Any issue with voltage, current, or frequency that manifests itself and causes failure or improper operation of customer equipment is referred to as a PQ problem.

Among the many PQ issues that industrial processes must deal with are voltage sags and swells. More serious voltage sags occur. Power industries have demonstrated over the past few decades that negative effects on the PQ may be reduced or avoided using traditional methods, and that methods utilizing quick controlled force commutated power electronics (PE) are even more effective. PQ compensators go within one of two categories. One is a harmonics-eliminating shunt linked compensation device. The other is a device that is series connected, which has an advantage over a shunt type for resolving voltage sags and distorted system side voltages brought on by power transmission system flaws. The STATCOM utilized in distribution systems is referred to as DSTACOM (Distribution- STACOM), and it has a similar configuration with a few minor adjustments. By adjusting the converter voltage's amplitude and phase angle with respect to the line terminal voltage, it can exchange both active and reactive power with the distribution system. A multilevel inverter can lower output harmonics and device voltage by boosting the number of output voltage levels. There are several types of multilevel inverters: cascaded H-bridge, neutral point clamped and flying capacitor. Because of their modularity and simplicity, CHB inverters are particularly popular among these topologies. CHB inverters can be modulated using a number of different techniques. By adding more H-bridges, CHB inverters may simply expand the number of output voltage levels. In this paper, a DSTATCOM-based CHB multilevel inverter with a proportional integral controller is presented for reducing harmonics and reactive power in nonlinear loads. Due to the increase in the number of voltage levels, low switching losses, low electromagnetic compatibility for hybrid filters, and higher order harmonic elimination, this type of arrangement has been widely used for PQ applications.

II. DESIGN OF MULTILEVEL BASED D-STATCOM

A. Principle of DSTATCOM

Figure 1 shows a schematic representation of a D-STATCOM (Distribution Static Compensator), which is made up of a two-level Voltage Source Converter (VSC), a dc energy storage device, and a coupling transformer linked in shunt to the distribution network. The VSC transforms the storage device's dc voltage into a series of three-phase ac output voltages. These voltages are connected with the ac system in phase thanks to the coupling transformer's reactance. Effective regulation of active and reactive power exchanges between the D- STATCOM and the ac system is made possible by appropriately adjusting the phase and magnitude of the D- STATCOM output voltages. A device with this setup can generate or absorb controllable active and reactive power.

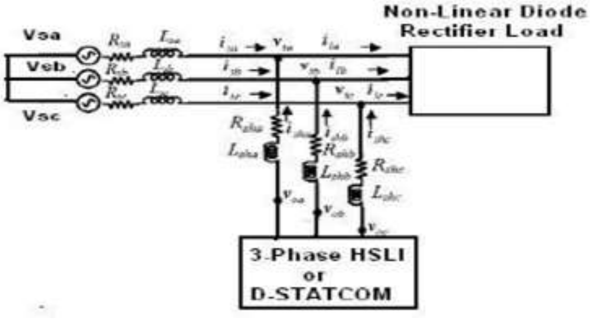


Figure 1: Schematic Diagram of a D- STATCOM

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power;
2. Correction of power factor
3. Elimination of current harmonics.

B. Control for Reactive Power Compensation

The control strategy's goal is to keep the voltage magnitude constant at the location of a connected sensitive load during system disruptions.

The control system only measures the rms voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching methods favoured in FACTS applications. Apart from this, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

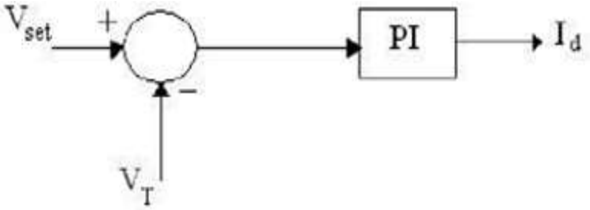


Figure 2: PI Control for Reactive Power Compensation

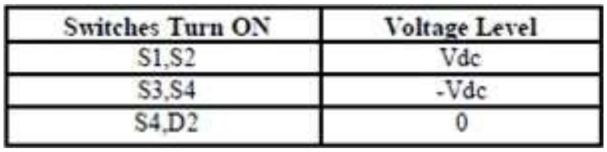
The reference voltage and the observed rms terminal voltage are used to create the error signal for the controller input. A PI controller handles this inaccuracy; it produces the angle, which is given to the PWM signal generator. It's crucial to remember that in this instance of an indirectly managed converter, the network receives both active and reactive power exchanges. The load rms voltage is returned to the reference voltage after the PI controller evaluates the error signal and generates the necessary angle to drive the error to zero.

Control for Harmonics Compensation: [7] presents the Modified Synchronous Frame technique. The instantaneous current component (id-iq) approach is what it is known as. The Synchronous Reference Frame theory (SRF) approach is comparable to this. The voltages of the ac network are now used to determine the transformation angle.

The main distinction is that the reference frame's speed is no longer constant because to voltage harmonics and imbalance. Depending on the waveform of the three-phase voltage system, it changes instantly. The instantaneous active and reactive current components of the nonlinear load are used in this method to calculate the compensating currents.

Similar calculations must be made for the major voltages V(a,b,c) and the available currents il (a,b,c) in - components, where C is the Clarke Transformation Matrix. However, an SRF based on the Park transformation is used to calculate the load current components, where “ denotes the instantaneous voltage vector angle (5).

Table 1: Switching Table of Single CHB Inverter



Switches Turn ON	Voltage Level
S1,S2	Vdc
S3,S4	-Vdc
S4,D2	0

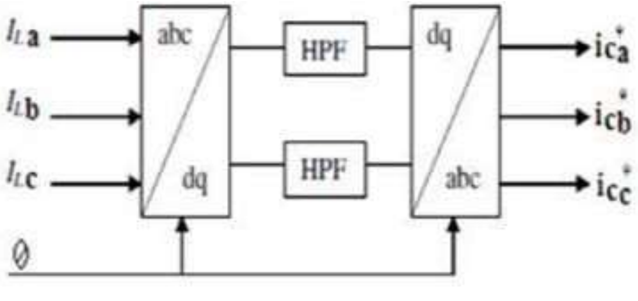


Figure 3: Block Diagram of SRF Method

C. Cascaded H-Bridge Multilevel Inverter

Fig.4 shows the circuit model of a single CHB inverter configuration. By using single H-Bridge we can get 3 voltage levels.

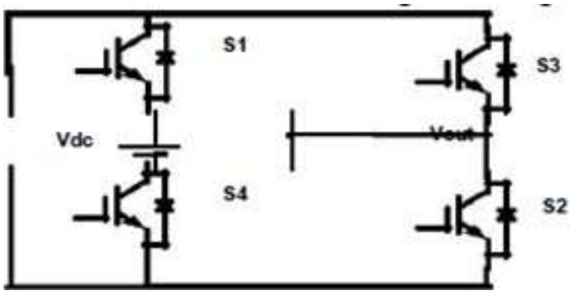


Figure 4: Circuit of the Single Cascaded H-Bridge Inverter

The number of output voltage levels of CHB is given by 2n+2 and voltage step of each level is given by Vdc/3n, where n is number of H-bridges connected in cascaded. The switching table is given in Table 1.

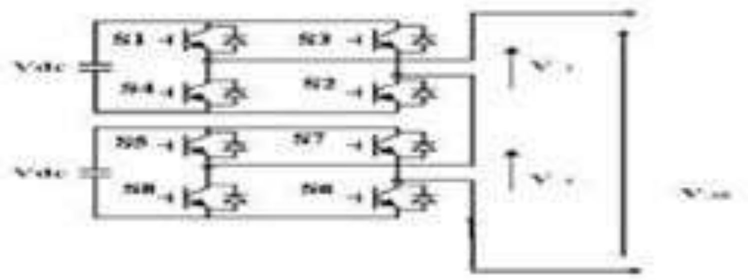
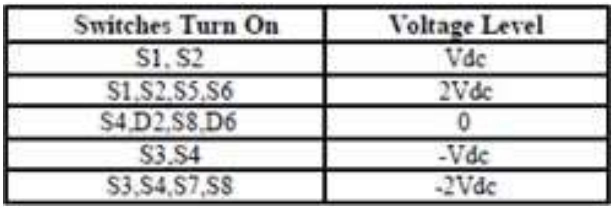


Figure 5: Block Diagram of 5-Level CHB Inverter Model

Table 2: Switching Mechanism for %-Level CHB Inverter



Switches Turn On	Voltage Level
S1, S2	Vdc
S1,S2,S5,S6	2Vdc
S4,D2,S8,D6	0
S3,S4	-Vdc
S3,S4,S7,S8	-2Vdc

D. PWM Techniques for CHB Inverter

The most popular PWM techniques for CHB inverter are 1. Phase Shifted Carrier PWM (PSCPWM), 2. Level Shifted Carrier PWM (LSCPWM).

Phase Shifted Carrier PWM (PSCPWM)

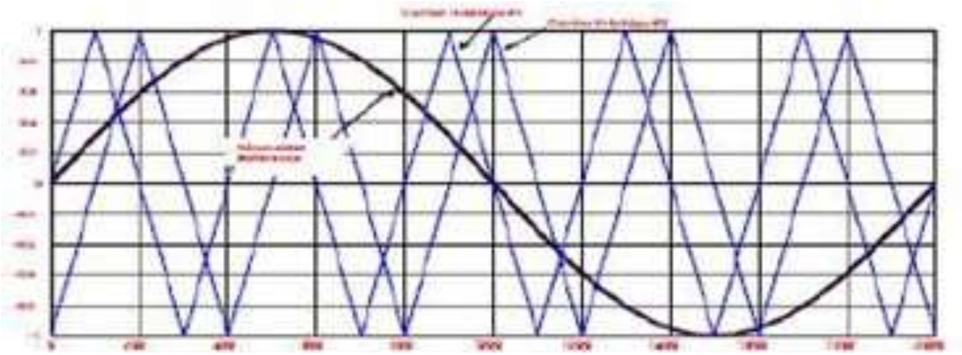
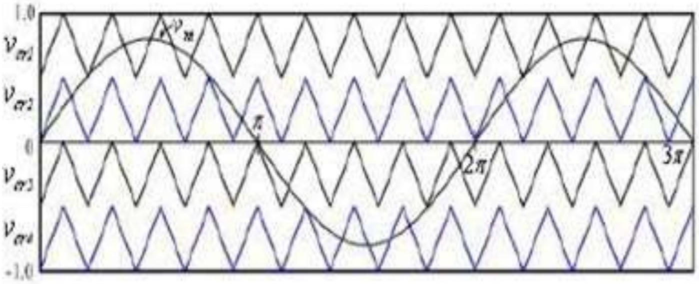


Fig. 6: Phase Shift Carrier PWM

Phase-shifted carrier pulse width modulation is depicted in Fig. 6. A uniform power distribution across the cells is achieved by independently modulating each cell using bipolar and sinusoidal pulse width modulation, respectively. To produce the stepped multilevel output waveform with less distortion, a carrier phase shift of 170°/m (number of levels) for cascaded inverter is added across the cells.



Level Shifted Carrier PWM (LSCPWM)

Fig. 7: Level Shifted Carrier PWM

The level-shifted carrier pulse width modulation is depicted in Fig. 7. An uniform power distribution across the cells is achieved by independently modulating each cell using bipolar and sinusoidal pulse width modulation, respectively. To produce the stepped multilevel output waveform with less distortion, a carrier Level shift by 1/m (No. of levels) for cascaded inverter is introduced across the cells.

III. MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

Here Matlab/Simulink model is developed for two cases. In case one DSATCOM with Linear load and in case two D-STATCOM with nonlinear load are simulated.

A. Case One

Fig. 9 shows the Matab/Simulink power circuit model of DSTATCOM. It consists of five blocks named as source block, non-linear load block, control block, APF block and measurements block.

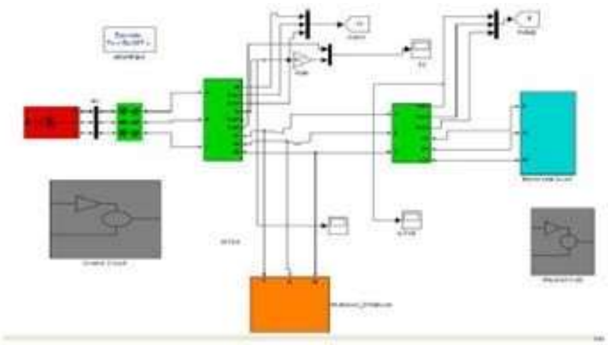


Fig. 8: Matlab/Simulink Power Circuit Model of DSTATCOM

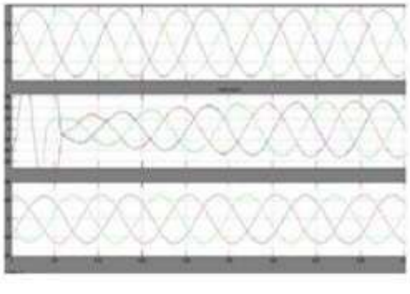


Fig. 9: Source Voltage, Current and Load Current with DSTATCOM

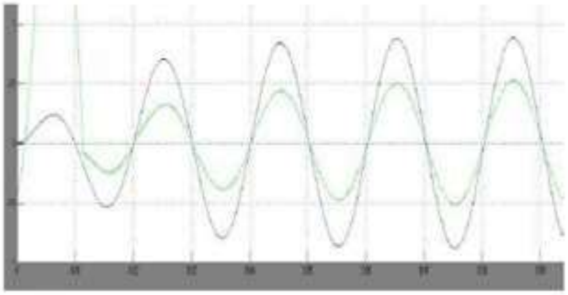


Fig. 10: Phase- A Source Voltage and Current

Fig. 10 shows the phase-A source voltage and current, even though the load is non-linear RL load the source power factor is unity.

B. Case Two

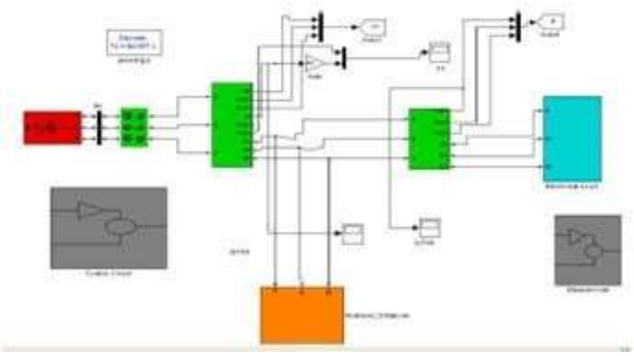


Fig. 11: Matlab /Simulink Power Circuit Model of DSTATCOM

Fig. 11 shows the phase-A voltage of 5 level output of phase shifted carrier PWM inverter.

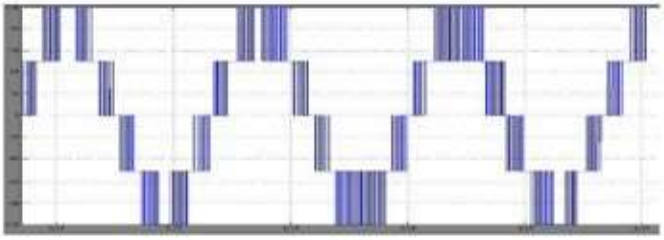


Fig. 12: Five Level PSCPWM Output

Fig. 13 shows the 3 phase source voltages, 3 phase source currents and load currents respectively without DSTATCOM. It is clear that without DSTATCOM load current and source currents are same.

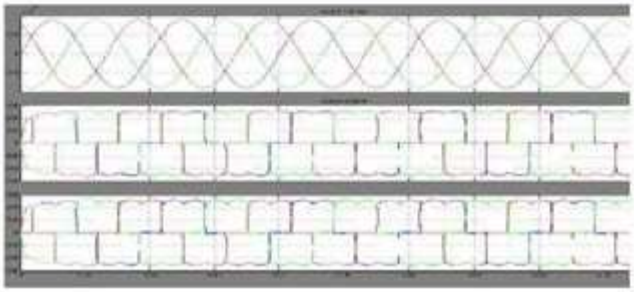


Fig. 13: Source Voltage, Current and load Current without DSTATCOM

Fig. 14 shows the three phase source voltages, three phase source currents and load currents respectively with DSTATCOM. It is clear that with DSTATCOM even though load current is non sinusoidal source currents are sinusoidal.

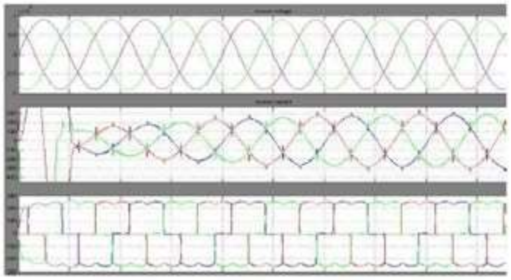


Fig. 14: Source Voltage, Current and load Current with D-STATCOM

Fig. 15 shows DC bus voltage. The DC bus voltage is regulated to 11kv by using PI regulator.

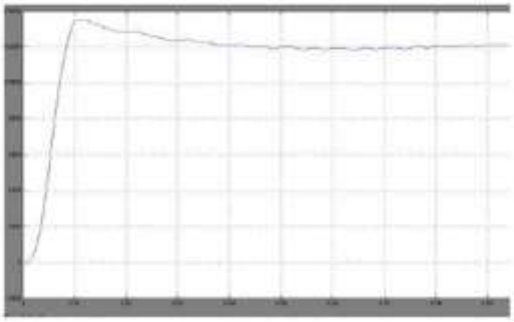


Fig. 15 DC Bus Voltage

Fig. 16 shows the phase-A source voltage and current, even though the load is non-linear RL load the source power factor is unity

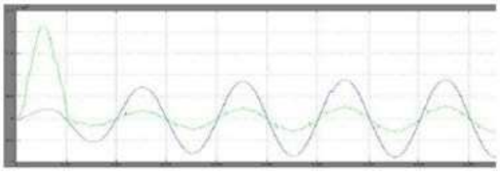


Fig. 16: Phase –A Source Voltage and Current

Fig. 17 shows the harmonic spectrum of Phase –A Source current without DSTATCOM. The THD of source current without DSTACOM is 36.99%.

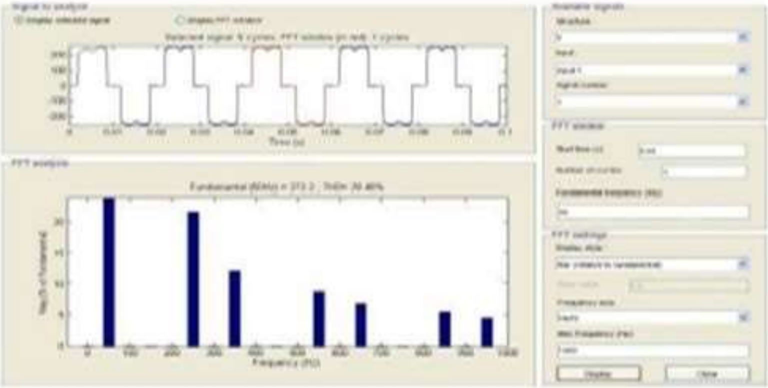


Fig. 17: Harmonic Spectrum of Phase-a Source Current without DSTATCOM

Fig. 18 shows the harmonic spectrum of Phase –A Source current with DSTATCOM. The THD of source current without DSTACOM is 5.15%

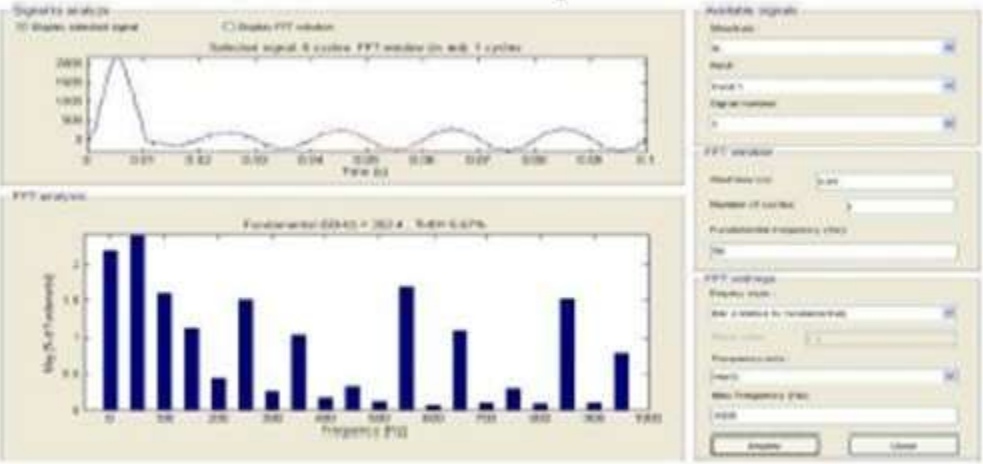


Fig. 18: Harmonic Spectrum of Phase-A Current with DSTATCOM

IV. CONCLUSION

This research examined a five-level inverter that was successfully tested in MatLab/Simulink and was employed in a D-STATCOM in PS. Low harmonic distortion, fewer switches required to create a seven-level inverter output compared to a cascaded seven-level inverter, and lower switching losses are all advantages of the five-level inverter. Investigated is a D- STATCOM with a five-level CHB inverter. A mathematical model for a single H-Bridge inverter that can be expanded to several H-Bridges is created. The simulation results for the source voltage, load voltage, source current, load current, and power factor for non-linear loads are reported. Finally, a model built on Matlab/Simulink is created, and simulation results for both linear and non-linear loads are presented.

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