A Novel Hybrid Power Conditioner for Mitigation of Harmonics and Neutral Line Current in Three Phase Four Wire Distribution System

Mayuri Vaijanath Atre, K. Chandra Obula Reddy

Abstract— ***In this paper, a novel hybrid power conditioner is proposed for suppressing harmonic currents and neutral-line current in three-phase four-wire distribution power systems. The proposed hybrid power conditioner is composed of a neutral-line current attenuator and a hybrid power filter. The hybrid power filter, configured by a three-phase power converter and a three-phase tuned power filter, is utilized to filter the nonzero-sequence harmonic currents in the three-phase four-wire distribution power system. The three-phase power converter is connected to the inductors of the three-phase tuned power filter in parallel, and its power rating can thus be reduced effectively. The tuned frequency of the three-phase tuned power filter is set at the fifth harmonic frequency. The neutral-line current suppressor is connected between the power capacitors of the three-phase tuned power filter and the neutral line to suppress the neutral-line current in the three-phase four-wire distribution power system. With the major fundamental voltage of the utility dropping across the power capacitors of the three-phase tuned power filter, the power rating of the neutral-line current suppressor can thus be reduced. Hence, the proposed hybrid power conditioner can effectively reduce the power rating of passive and active elements. A hardware prototype is developed to verify the performance of the proposed hybrid power conditioner. Experimental results show that the proposed hybrid power conditioner achieves expected performance.***

Index Terms: Harmonic, neutral-line current, power converter

I. INTRODUCTION

The power quality problems in power utility distribution systems are not new, but recently their effects have gained public awareness. Advances in semiconductor device technology have fuelled a revolution in electronics and power electronics over the past decade, many factories and heavy loads which are recently installed highly affect power quality due to their non sinusoidal current. Power electronics equipments are responsible for raising the power quality problems. These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system.

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Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the point of common coupling (PCC). As the harmonic currents pass through the line impedance of the system, harmonic voltages appear, causing voltage distortion at the PCC. Harmonics have a number of undesirable effects on the distribution system like malfunctioning of electronic equipment, capacitor failure, transformer and neutral conductor overheating, excessive heating in rotating machinery etc. The third harmonic is very serious in single-phase nonlinear loads. The third-order harmonic current of each phase is synchronous and regarded as the zero-sequence current. Therefore, the zero-sequence currents of each phase are summed up and flow into the neutral line of three-phase four-wire distribution power systems. Furthermore, single-phase loads may result in serious load unbalance, and the unbalanced load current also flows into the neutral line of the three-phase four-wire distribution power systems. In many applications, the neutral-line current will exceed the phase currents. Excessive neutral-line current may cause accidents due to overload of the neutral line. Moreover, it will lead to fluctuation in ground voltage of the load, which may influence the operation of precision equipment. Hence, the major problems of three-phase four-wire distribution power systems are harmonic currents and neutral-line current [1], [2]. To overcome the above problems, controlling limits for Total Harmonic Distortion are fixed in the international standards such as IEEE 519 1992.To control the Total Harmonic Distortion in the system conventional as well as hybrid power filters are being used in these days. In hybrid power filters of the shunt type, the power converter is connected to the passive power filter in series and then connected to the load in parallel [18]-[21].The major part of the utility voltage will drop on the passive power filter. In this way, the dc bus voltage and voltage rating of the power converter can be significantly reduced. However, the current of the power converter, including the harmonic currents of the load and the fundamental reactive current of the passive power filter, is not diminished. Although the shunt-type hybrid power filter can be applied to improve problems of the neutral-line current in three-phase four-line distribution power systems[21], it cannot attenuate the fundamental component of neutral-line current caused by the unbalanced load. In addition, the current of the power converter is not diminished yet. A novel hybrid power conditioner for solving the problems of harmonic currents and neutral-line current in three-phase four wire distribution power systems is proposed.

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This hybrid power conditioner is configured by a neutral-line current attenuator and a hybrid power filter. The hybrid power filter, configured by a three-phase power converter and a three phase tuned power filter, is utilized to filter the non zero-sequence harmonic.

currents in the three-phase four-wire distribution power system. The neutral-line current suppressor is connected between the power capacitors of the three-phase tuned power filter and the neutral line to attenuate the neutral-line current in the three-phase four-wire distribution power system. The proposed hybrid power conditioner can effectively reduce the power rating of passive and active elements. A hardware prototype is developed to verify the performance of the proposed hybrid power conditioner.

II. CONVENTIONAL SHUNT TYPE HYBRID FILTER

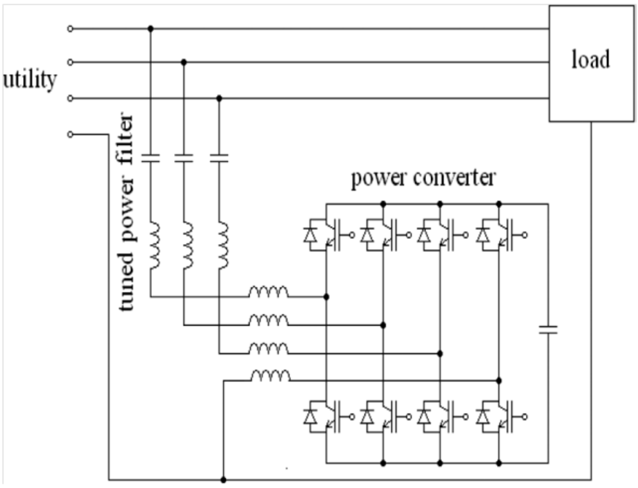

Fig. 1.Conventional Shunt Hybrid Power Filter.

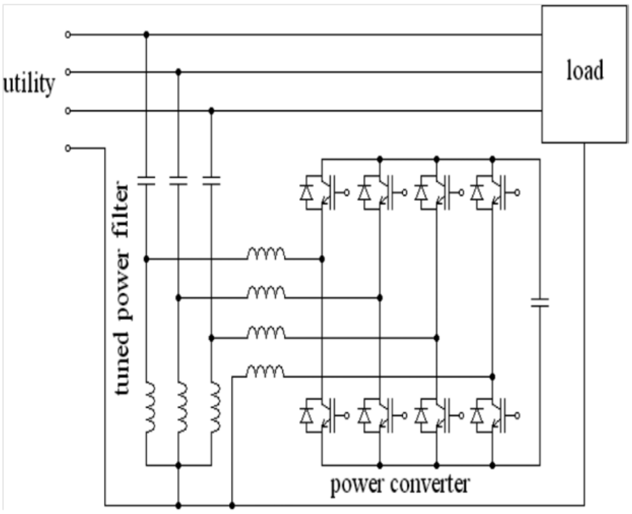

Fig. 2 Advanced Hybrid Power Filter

Fig. 1 shows the configuration of a conventional shunt-type hybrid power filter applied to the three-phase four-wire distribution power system. In the conventional shunt-type hybrid power filter, the power converter is connected to the passive power filter in series and then connected to the load in parallel[18]–[21]. The power converter can be configured by a four-arm bridge structure or a three-arm bridge structure with a split-capacitor arm. The passive power filter is configured by three-phase tuned power filters with an inductor and a capacitor connected in series in each phase, and their tuned frequency is the dominant harmonic frequency of the load. The tuned frequency of the tuned power filters is designed at the third harmonic frequency in the application of three-phase four-wire distribution power systems. As seen in Fig. 1, the major part of the utility voltage will drop on the passive power filter. In this way, the dc bus voltage and voltage rating of the power converter can be significantly reduced. However, the current of the power converter, including the harmonic currents of the load and the fundamental reactive current of the passive power filter, is not diminished. An advanced hybrid power filter, shown in Fig. 2, is proposed to further reduce the power rating of the power converter [22]–[25]. As seen in Fig. 2, the power converter is connected to the inductors of the three-phase tuned power filter in parallel. Since the power converter is parallel to the inductors of the tuned power filters, the major fundamental reactive current of the three-phase tuned power filter and the dominant harmonic current of the load will flow through the inductors of the three-phase tuned power filter by proper control of the power converter, thus decreasing the current flowing through the power converter. The major role of the conventional shunt-type hybrid power filter applied to the three-phase four-wire distribution power system is to filter harmonic currents of the load. If the three phase loads are unbalanced, the neutral-line current of the load contains a fundamental component. The conventional shunt type hybrid power filter cannot respond to this fundamental component of the neutral-line current. Therefore, it cannot effectively suppress the neutral-line current under the unbalanced load.

III. SYSTEM DEVELOPMENT

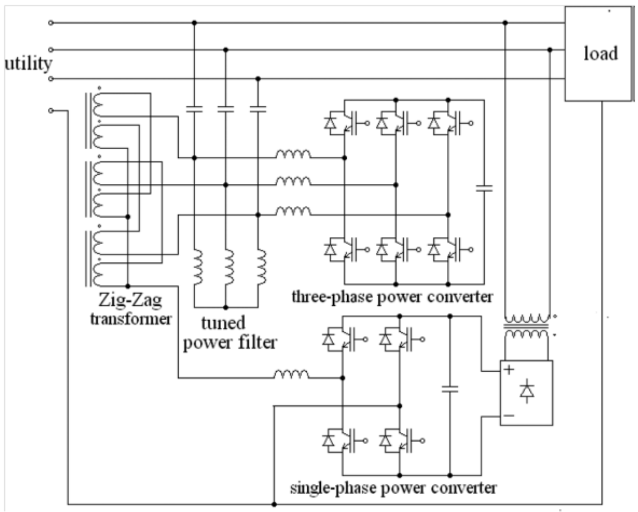

Fig 3.System Configuration of Proposed Hybrid Power Filter

Fig. 3 shows the system configuration of the proposed hybrid power conditioner. In comparison with the conventional hybrid power filter, a neutral-line current attenuator is integrated into the hybrid power filter in the proposed hybrid power conditioner. The integrated neutral-line current attenuator can advance the filter performance of the hybrid power filter under the unbalanced load.

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Hence, the proposed hybrid power conditioner can simultaneously and effectively solve the problems of harmonic currents and neutral-line current in three-phase four-wire distribution power systems. To further reduce the power rating of the power converter, the advanced hybrid power filter is used with the three-phase power converter connected to the inductors of the three-phase tuned power filter in parallel.

By incorporating the neutral-line current attenuator, the hybrid power filter is utilized to suppress only the nonzero-sequence harmonic currents in three-phase four wire distribution power systems. Hence, the three-phase power converter is configured by a three-arm bridge structure and the tuned frequency of three-phase tuned power filter is set at the fifth harmonic frequency. With an increase in tuned frequency of the tuned power filters, the inductance of inductors can be reduced. Consequently, the volume and weight of the three phase tuned power filter are reduced.

The neutral-line current attenuator of the hybrid power conditioner is employed to suppress the neutral-line current. Conventionally, the neutral-line current attenuator is connected between three-phase lines and the neutral line of the three-phase four-wire utility [6]. Hence, the voltage rating of the zig-zag transformer used in the conventional neutral-line current attenuator is the phase voltage of the three-phase four-wire utility, thus enlarging the volume and weight of the zig-zag transformer. As can be seen in Fig. 3, the neutral-line current attenuator is connected to the capacitors of tuned power filters in series, and the fundamental component of phase voltage will drop on these capacitors. The voltage rating of the zig-zag transformer is almost equal to the voltage of inductors in the tuned power filters, and its voltage is very small compared with the zig-zag transformer used in the conventional neutral-line current attenuator. Hence, the volume and weight of the zig-zag transformer used in the proposed neutral-line current attenuator are reduced. The single-phase power converter is connected to the zig-zag transformer in series to advance the performance of the zig-zag transformer. As seen in Fig. 3, the neutral line of the load is directly connected to that of the utility, and the fluctuation in ground voltage of the load can thus be avoided. Owing to power loss caused by the operation of the single-phase power converter, the dc bus voltage of the power converter is decreased. However, the power loss is low because the dc bus voltage of the single-phase power converter is low. A simple single-phase diode rectifier is employed to supply power to the dc bus of the single-phase power converter to sustain the dc bus voltage at an acceptable range. A transformer is employed to step down the line-to-line voltage. The input current of the single-phase diode rectifier is small.

IV. CONTROL PRINCIPLE AND CONTROL BLOCK DIAGRAM

To control the three-phase power converter of the hybrid power filter current-mode control is adopted. The output currents of the three-phase power converter are controlled to be

$$I_{ca} = k_1 I_{sah} + k_2 V_{sa1} \quad \text{..........(1)}$$

$$I_{cb} = k_1 I_{sbh} + k_2 V_{sb1} \quad \text{..........(2)}$$

$$I_{cc} = k_1 I_{sch} + k_2 V_{sc1} \quad \text{..........(3)}$$

Where Isah, Isbh, Isch are the harmonic components of the three-phase utility currents, Vsa1,Vsb1, Vsc1are the three phase fundamental voltages of the utility. As seen in (1)–(3), the first term is for suppressing the nonzero-sequence harmonics, and the second term is for regulating the dc bus voltage of three-phase power converter. Since the three-phase power converter is parallel to the inductors of the three-phase tuned power filter and its output currents are controlled as (1)–(3), the major fundamental reactive currents of the tuned power filters and the dominant harmonic currents of the load will flow through the inductors of the tuned power filters. Therefore, the currents flowing through the three-phase power converter can be effectively decreased.

The single-phase power converter of the neutral-line current attenuator is controlled by the general pulse width modulation (PWM), and its output voltage can be represented as

$$V_{con} = K_{con} V_m \text{.................(4)}$$

Where, K con is the gain of the single-phase power converter, and Vm is the modulation signal of the PWM circuit.

The gain of the single-phase power converter can berepresented as

$$K_{con} = V_{dc} / V_{tri} \text{.................(5)}$$

Where, Vdc the dc is bus voltage of the single-phase power converter, and Vtri is the amplitude of the carrier of the PWM circuit.

The single-phase power converter adopts the simple feedforward control. The neutral-line current of the utility is detected, amplified, and sent to the PWM circuit as the modulation signal, and the output voltage of the power converter can be derived as

$$V_{con} = K_{con} K_3 I_{sn} \text{.....................(6)}$$

Where K3 is the feedforward gain.

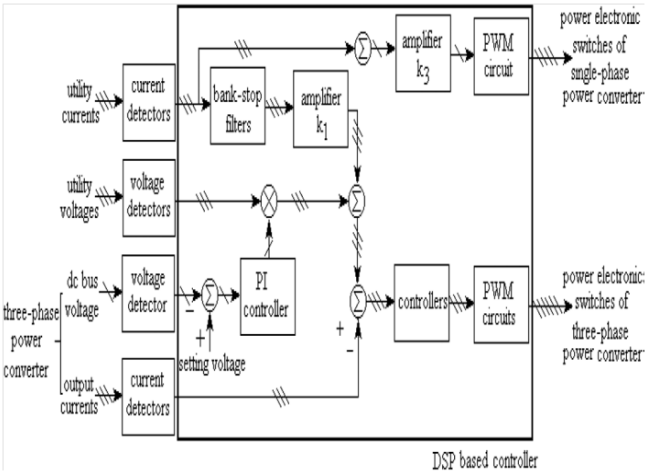

Fig 4.Control Block Diagram for Power Converters

Fig 4. shows the control block diagram of three-phase and single-phase power converters. The three-phase power converter adopts the current-mode control. The current references should be calculated first. The current references should be equal to (1)–(3), and they contain a fundamental signal and a harmonic signal.

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The detected three-phase utility currents are sent to the band stop filters to extract their harmonic components. The outputs of the band stop filters are sent to the amplifier with gain , and the harmonic signals of the current references are then obtained. The detected dc bus voltage of the three-phase power converter is compared with the setting voltage, and the compared result is sent to a proportional-integral(PI) controller. The output of the PI controller is . Both the outputs of the PI controller and the detected three-phase utility voltages are sent to the multipliers so that the fundamental signals of the current references are obtained.

The current references are obtained by summing up the harmonic signals and the fundamental signals. The detected output currents of the three-phase power converter are compared with the current references, and the compared results are then sent to the controllers. The outputs of the controllers are sent to the PWM circuits to generate the driver signals of the power-electronic switches for the three-phase power converter. The feed forward control is employed to control the single phase power converter. The neutral-line current of the utility can be obtained by summing up the detected three-phase utility currents and is then sent to an amplifier of gain . The output of the amplifier is sent to the PWM circuit to serve as the modulation signal. The PWM circuit adopts unipolar PWM to generate four PWM signals for the power-electronic switches of the single-phase power converter. The control blocks of three-phase and single-phase power converters can be integrated into a digital-signal-processor (DSP) chip.

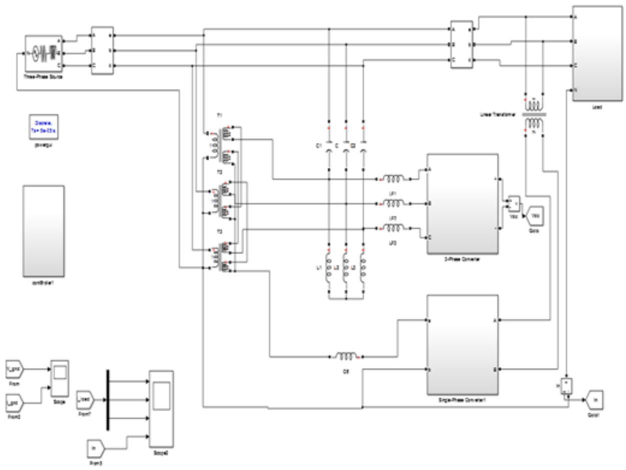

Fig 5. Matlab/ Simulink Model for Hybrid Power Conditioner

Table I. Main Parameters of Prototype

Tuned Power Filter			
Inductor	2.5mH	Capacitor	130 μF
Three Phase Power Converter			
Switching frequency	20kHz	Filter Inductor	2 mH
Dc BusVoltage	80 V	Dc Capacitor	3000 μF
Single Phase Power Converter			
Switching frequency	20kHz	Filter Inductor	2 mH
Dc BusVoltage	80 V	Dc Capacitor	3000μF

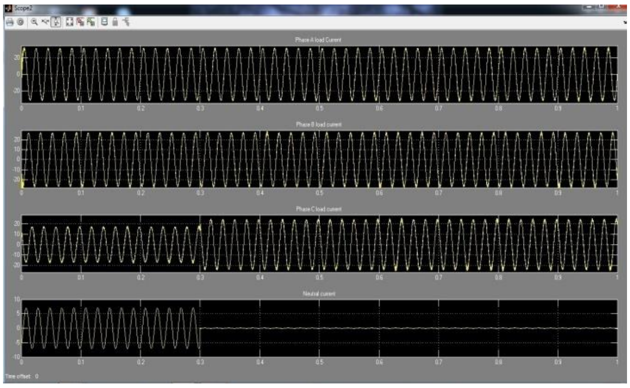

Fig 6. Waveforms of three phase four-wire hybrid power conditioner under the transient of applying the neutral-line current attenuator (a)Phase a load current (b) phase b load current (c) phase c load current (d)neutral line current line current of load.

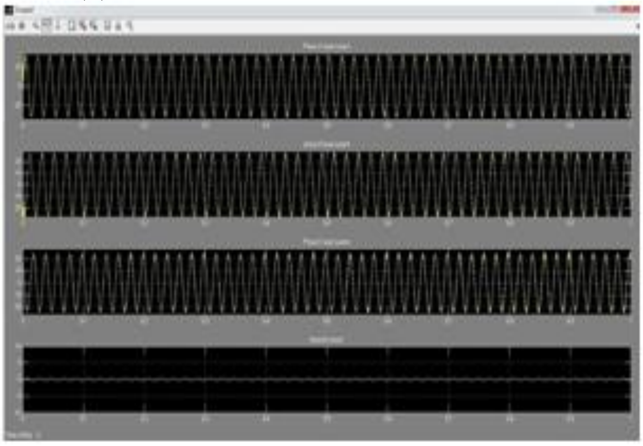

Fig 7. Waveforms of three phase four-wire hybrid power conditioner under the balanced three phase load (a) Phase a load current (b) phase b load current (c) phase c load current (d)neutral line current line current of load.

V. SIMULATION RESULTS

The main parameters of the prototype are shown in Table I. Figs. 6 and 7 show the experimental results of the three-phase four-wire hybrid power conditioner under the transient of applying the neutral-line current attenuator and the balanced load. The total harmonic distortion (THD %) of load current and neutral current is 2.27%, 2.65%, 3.38% and 0.16% respectively. Hence, it verifies that the proposed hybrid power conditioner can suppress the harmonic currents and attenuate the neutral-line current effectively even when the load is unbalanced.

VI. CONCLUSION

In the hybrid power conditioner, the power capacity of power converters in the hybrid power filter and neutral-line current attenuator can be effectively reduced, thus increasing its use in high-power applications and enhancing the operation efficiency. A prototype is developed and tested. Experimental results verify that the proposed hybrid power conditioner can suppress the harmonic currents and attenuate the neutral-line current effectively whether the loads are balanced or not.

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Hence, the proposed hybrid power conditioner is an effective solution to the problems of harmonic currents and neutral-line current in three-phase four-wire distribution power systems. Besides, the output current of the three-phase power converter is much smaller than the conventional hybrid power filter, and the power rating of the zig-zag transformer is smaller than the rating of the conventional neutral-line current attenuator.

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