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A Method to Reduce Neutral Current in Three Phase Four Wire Electric Distribution Systems by Using Active Power Filter

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Abstract: Neutral current in three-phase power systems is often thought to be only the result of the imbalance of the phase currents. With computer systems, very high neutral currents have been observed even when the phase currents are balanced. Recent surveys of 415V/230V three-phase four-wire electric systems, buildings and industrial plants with computers and nonlinear loads show excessive currents in the neutral. These neutral currents are fundamentally third harmonic and their presence is tied to wiring failures, elevating of neutral potentials, transformer overheating, etc. In response to these concerns, this paper proposes a active power filter scheme to cancel neutral current. The closed loop control of the active power filter guarantees cancellation of neutral current harmonics under varying load conditions. The neutral current In is sensed via a current sensor and is processed through a 50 Hz notch filter in order to remove any fundamental current component in In. The filtered current signal is then compared with Iref., which is set to zero. The resulting error signal is fed to the PWM control logic in order to inject an equal and opposite current In, thereby achieving cancellation in closed loop. This current injection technique neutralizes any harmonic current that is flowing in the neutral. The circuit is simulated and the result is verified with MATLAB7/SIMULINK.

Key words: Neutral current % Active Filter % Filter current

INTRODUCTION

On three-phase wye power systems, neutral current is the vector sum of the three line-to-neutral currents. With balanced, three-phase, linear currents, which consist of sine waves spaced 120 electrical degrees apart, the sum at any instant in time is zero and so there is no neutral current as shown in Fig. 1. In most of the three-phase power systems supplying, single-phase loads, there will be some phase current imbalance and some neutral current. Small neutral currents resulting from slightly unbalanced loads do not cause problems for typical building power distribution systems. There are conditions where even perfectly balanced single-phase loads can result in significant neutral currents. Nonlinear loads, such as rectifiers and power supplies, have phase currents which are non- sinusoidal. The vector sum of balanced, nonsinusoidal, three-phase currents does not necessarily equal zero. For example, balanced square-wave currents will result in significant neutral current as shown in Fig. 2. Typical loads connected to a low voltage three-phase four-wire system include:

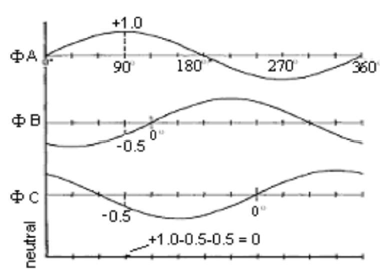

Fig. 1: Balanced linear 3-ph loads results in zero neutral current.

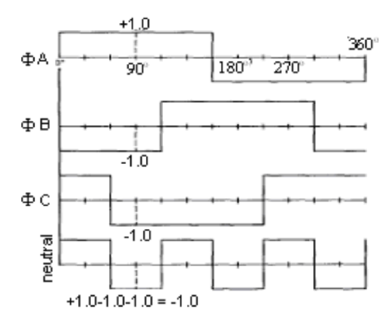

Fig. 2: Example of balanced 3-ph loads having neutral current.

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adjustable speed.heating ventilation and air-conditioning (HVAC) systems, fluorescent lighting circuits with conventional and electronic ballasts, computers for data processing and office automation, as well as many other sensitive electronic loads. Almost all of the above applications employ switched mode type power electronic converters which draw excessive harmonic currents of which a significant portion is the third harmonic (150 Hz) component. Further, saturated iron-cored inductive ballasts as well as electronic ballasts in fluorescent lighting circuits also contribute to third harmonic currents [l]. The third harmonic and odd multiples of 3rd (i.e., 9th, 15th, etc.) do not cancel each other in the neutral. The result is, in fact, a cumulative addition and the primary source for excessive neutral currents in modern three phase fourwire distribution systems.

A recent survey conducted by Liebert Customer Service engineers in 146 computer sites across the country evealed that 22.6% of the sites had neutral currents in excess of 100% of the phase current [2]. These results also concur with the survey conducted by the computer and business equipment manufacturers association (CBEMA) [3]. CBEMA recently published a white paper warning that a shared neutral conductor in modern buildings may carry increased harmonic currents and result in wiring failures [4]. Potential problems directly related to excessive harmonic currents in the neutral conductor are

- Wiring failure due to improper sizing of the neutral conductor,
- Overheating of the transformer due to harmonic currents and insulation damage and failure,
- Intermittent electrical noise from connections loosened by thermal cycling,
- Excessive neutral to ground voltage due to a voltage drop caused by the neutral current.

This common mode potential can result in the malfunction of sensitive electronic components. Both Liebert Corporation and CB EMA recommend the following practices and corrective measures [3, 4].

- Derate transformers.
- Use separate neutral conductors for nonlinear loads
- Use neutral over current sensors to trip phase conductors.
- Use true rms ammeters and instruments with sufficient bandwidth for measurement.

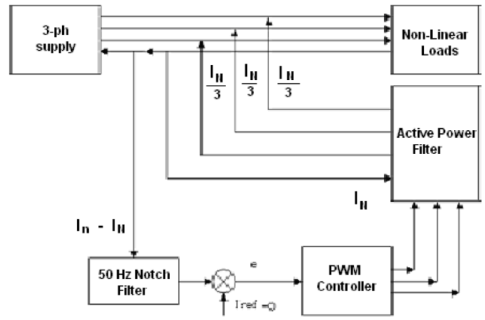

Fig. 3a: The proposed active filter topology

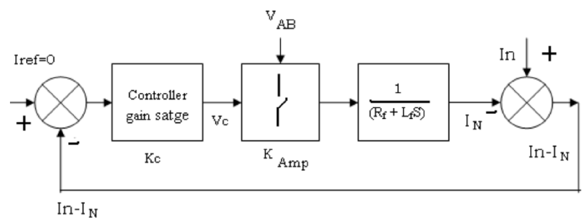

Fig. 3b: Closed loop block diagram.

Proposed Active Power Filter to Cancel Neutral Current Harmonics: The proposed active power filter configuration is shown in Fig. 3a. The operation of the active power filter is as follows; the neutral current In, is sensed via a current sensor and is processed through a 50 Hz notch filter in order to remove any fundamental current component in In. The filtered current signal is then compared with Iref, as shown in fig. 3b, which is set to zero. The resulting error signal is feed to the PWM control logic in order to inject an equal and opposite current IN, thereby achieving cancellation in closed loop. This current injection technique neutralizes any harmonic current that is flowing in the neutral and thus protects the upstream distribution system and transformer. Hence, if the filter is canceling 100% of the neutral current, then IN = In. The inductor Lf is selected to filter the switching harmonics caused by the PWM operation. The advantages of this proposed approach are as follows.

- Active power filters offer continuous measurement and cancellation of neutral current Harmonics.
- Active power filters do not consume any real power other than that required to account for internal losses. The proposed active power filter is expected to be over 90% efficient.
- The proposed system can adapt to changing load conditions.
- The proposed active power filter has fast response characteristics and sufficient bandwidth to cancel several zero sequence harmonics appearing in the

neutral. The proposed active power filter operates at a high frequency (= 20 kHz) and an input filter stage can be designed to bypass the switching harmonics, thereby avoiding interference with the line.

- The active power filter employs state-of-the art power semiconductor devices and therefore is compact, light in weight and occupies less space.

Closed Loop Current Cancellation System Configuration: The closed loop system configuration is illustrated in Fig. 3.a. Following the block diagram shown in Fig. 3(b), the system operates as follows. The current flowing in the neutral In, - IN is sensed, passed through a 50 Hz notch filter and the compared with reference level is set to zero as the desired neutral current is zero. The error resulting from the comparison is then amplified in the controller gain stage Kc, which in turn controls the power-switching block KAMP. The control signal Vc is, obtained after the controller gain stage Kc, is used as the modulating signal and is compared with a high frequency (20 kHz) triangular wave in order to get the gating commands for the inverter switches. Hence, if the peak amplitude of the triangular wave is AT then

$$K_{AMP} = \frac{V_C * V_{AB}}{2A_T} \quad (1)$$

Finally, the current injected by the active power filter IN, is compared with the actual neutral current In. The resulting error produces a new neutral current In - IN, that is again compared with Iref in order to generate an error signal. In closed loop, the measured error is reduced to near zero and the neutral current harmonics are effectively cancelled by the active power filter. Further, the closed loop continues to respond to changes in load conditions and suitably provides continuous cancellation.

Approximate modeling of the closed loop control system suggests that it is a first order system. From Fig. 3(b), the open loop transfer function between the controlled output and error signal is given by [5].

$$G_1(S) = \frac{(I_n - I_N)(S)}{e(S)} = \frac{K_C K_{AMP}}{R + SL_f} \quad (2)$$

The corresponding closed loop transfer function can be expressed as

$$\frac{(I_n - I_N)(S)}{I_{erf}(S)} = \frac{K_C K_{AMP}}{R + SL_f + K_C K_{AMP}} \quad (3)$$

where

Kc = Controller gain
Kamp = Gain in the PWM inverter
Lf = Filter inductor
R = Resistance in the current path

The closed loop transfer function between the controlled output In-IN and input In is given by

$$\frac{(I_n - I_N)(S)}{I_N(S)} = \frac{R + SL_f}{R + SL_f + K_C K_{AMP}} \quad (4)$$

The value of the gains Kc and Kamp determine the amount of corrective effort which is applied for a given magnitude of error. For low values of controller gain, the corrective effort is small and hence the response is likely to be slow. As gain is increased, the response of the system for the same magnitude of error increases. On the other hand, if Kc is too large, instability is likely to result. Therefore, the magnitude of the steady-state error and the value to which the error signal tends as the transient disturbance from any input change dies out are both of importance since they are a measure of system accuracy. The steady state error ess, due to a step change in input, is given by

$$e_{ss} = \underset{s \to 0}{Lt} \frac{1}{1 + \frac{K_C K_{AMP}}{R + SL_f}} = \frac{1}{1 + K_P} \quad (5)$$

Where

$$K_P = \frac{K_C K_{AMP}}{R} \quad (6)$$

Thus, the steady-state error of the first order system is finite. Suitable values of the loop gain Kp,are selected in order to obtain a low steady-state error [5].

Simulation: The three phase fully controlled converter with RL-load, single phase fully controlled converter with RL-load and three phase unbalanced linear load are considered for proposed work. The proposed work is simulated with MATLAB7/SIMULINK for various combinations.Fig 4. Shows neutral current before compensation (Case-I), Fig 5. Shows harmonic current IN injected by the proposed active filter in order to cancel neutral harmonics (Case-I) and Fig 6. Shows neutral current after compensation (Case-I).

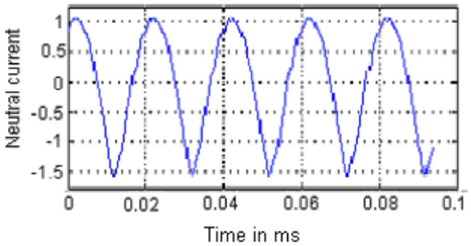

Fig. 4: Neutral current before compensation (Case I).

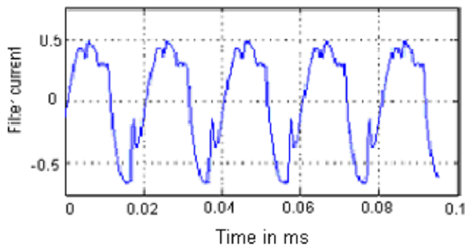

Fig. 5: Active Filter Current (Case I)

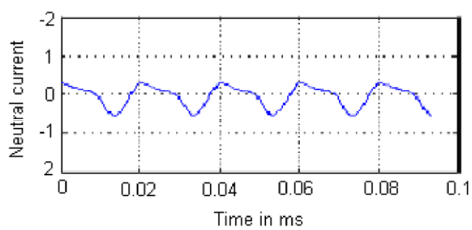

Fig. 6: Neutral current after compensation (Case I).

CONCLUSION

In this paper, an active power filter to cancel neutral currents in the three-phase four-wire system has been proposed. The proposed active power filter displays the ability to effectively cancel undesirable excessive currents flowing in the neutral line of a three-phase four-wire system and is highly efficient. The proposed topology drastically improves the system performance, contributes to efficient use of electric energy and virtually eliminates excessive heating of distribution transformers due to neutral currents. The circuit is simulated with MATLAB7/SIMULINK and the satisfactory results are obtained.

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