OTA – Based Control System of Active Power Filter for Harmonic and Reactive Power Compensation

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Abstract - This paper presents an OTA – based control system of active power filter for harmonic and reactive power compensation in power system. An SCR-full wave rectifier is used as an uncontrolled nonlinear load. A single phase control of shunt –CSI-APF [1] is discussed for simplicity. This proposed OTA-based control circuit [2]-[4] has the advantage of self-tuning, low cost, simple and small size circuitry compared to the use of high precision multiplier or digital processor. Theoretical analysis, design and simulation results of the OTA-circuit are provided. A prototype is being developed to demonstrate the performance of the control system [5].

I. INTRODUCTION

The uses of nonlinear load power electronic component connected to power systems cause the harmonic currents to change from a sinusoidal current to a non-sinusoidal current. Harmonic voltage results from the harmonic currents interacting with the impedance of the power system according to Ohm's law. Effect of harmonics voltage and current on equipment results in power quality problem [6]-[7] not only the end user or the utility serving the end user but also on the other end users.

Reactive power caused by inductive load represents wasted electrical energy. Nonlinear loads not only generate harmonics but also shift the phase angle between the load current and supply voltage, require reactive power to serve them, and cause lower power factor [8]-[24].

Active Power Filter (APF) has been developed for reactive power reduction and harmonic filtering by using electronic means, bridge inverter and rectifier , to inject the current for reactive power and harmonic compensation. The analysis and comparison of passive and active harmonic filtering was presented in [13].

Several methods of using APF have been researched and developed, shunt active filter using voltage source inverter (VSI) [8], [10]-[12], [16]-[17] and current source inverter (CSI) [9], [18] are widely used.

The series active filter and hybrid active filter (passive and series active) [14] are also have been researched but mainly employed to eliminate voltage flicker and unbalance problem.

The control systems using DSP – based [15]-[17] and ADALINE – based [18] have been used to improve the performance of the APF. However, simple control circuits using analog signal processing component [9], [11] are still be developed to reduce the cost and circuit complexity.

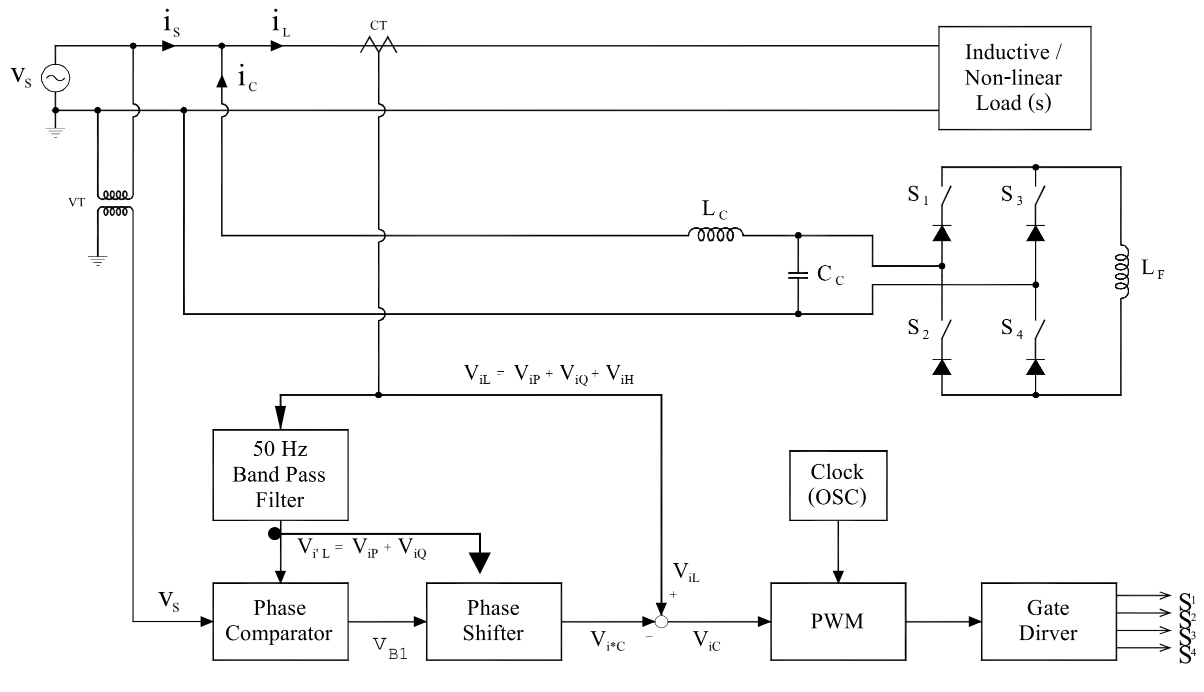

Fig.1 Schematic Diagram of APF and the Proposed Control Strategy

In recent years, OTA (Operational Transconductance Amplifier) have been implemented for working at high frequency, electronically tunable and simpler structure. OTA – based analog circuits also have advantages such as low power consumption, noise, parasitic effects and cost compared to the conventional op-amp. OTA can also have an application of analog band pass filter, phase comparator and phase shifter that are the keys control of APF.

This paper presents shunt-CSI-APF control method using simple OTA – based analog circuits for the control blocks of reference current calculation, comparison, current control and Pulse Width Modulation to generate the gate control signal APF. The use of OTA – based circuits provided a low cost compared to the use of high precision multiplier and high performance compared to the use of op-amp circuitry.

II. PROPOSED APF POWER CIRCUIT AND CONTROL SCHEMATIC DIAGRAM

Fig.1 shows the control circuit of the shunt current source inverter (CSI) active power filter connected to the ac voltage source, v_S, supplying the inductive/non linear load current i_L.

The expected performance of APF is to maintain the main current, i_S, as a sine wave and in-phase with the main voltage.

APF is controlled by OTA circuit in order to generate the required compensation current, i_C.

The control schematic block diagram is described by equations belows :-

Voltage source is represented as

$$v_S(t) = V_S \sin \omega t \tag{1}$$

Non linear load current can be represented as

$$i_L(t) = \sum_{h=1}^{\infty} I_h \sin(h\omega t + \theta_h) \tag{2}$$

$$= i_H + i_Q + i_P$$

Where, i_H represented harmonic current,
i_P represented fundamental active current,
i_Q represented fundamental reactive current.

The compensation current can be represented as

$$i_C(t) = i_L(t) - i_S(t) \tag{3}$$

Assuming voltage source supply only pure sinusoidal current and in phase with the voltage

$$i_S(t) = I_S \sin \omega t = i_P \tag{4}$$

Therefore, the compensation current from (3) is given by

$$i_C = i_L(t) - I_S \sin \omega t \tag{5}$$

$$= i_L(t) - i_P = i_H + i_Q \tag{6}$$

from PWM theory; $\frac{i_{Lf}(t)}{v_{iC}(t)} = \frac{I_{Lf\ avg}}{V_{tri}}$ (7)

gating signal $v_{iC}(t)$ *will be selected accordingl y*

OTA circuit are introduced for the determination of reference voltage v_{i*S} using band pass filter, phase comparator and phase shifter circuit concepts as belows :-

1) To eliminate harmonic current, v_{iH} can be determined by using BPF circuit, v_{iL} represents input voltage of the BPF, $v_{i'L}$ represented output voltage of the BPF which the harmonic currents in the form of harmonic voltage are eliminated. So that v_{iH} can be determined by

$$v_{iH} = v_{iL} - v_{i'L} \tag{8}$$

2) To eliminate reactive current, v_{iQ} can be determined by using phase shifter circuit.

$$v_{i'L} = v_{iP} + v_{iQ} \tag{9}$$

v_{i*S} is calculated as the reference voltage that in phase with the v_S so that the reactive voltage is eliminated from the $v_{i'L}$, so that

$$v_{iC} = v_{iL} - v_{i*S} = v_{iQ} + v_{iH} \tag{10}$$

III. ANALYSIS OF EACH BLOCK

A. OTA-C-Based 50 Hz – Band Pass Filter (BPF)

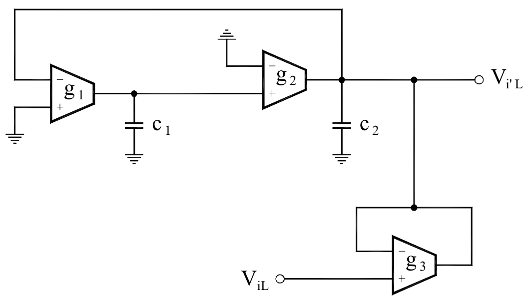

Fig.2 OTA-C Tow-Thomas Band Pass Circuit

Fig.2 shows the 2nd order OTA-C Tow Thomas Band Pass Filter [2] using 3 OTAs to give orthogonally tune characteristic.

Pass band filter at 50 Hz center frequency is selected to define the fundamental current i'_L in the form of voltage $V_{i'L}$.

Load current, i_L, is detected as voltage signal (by using CT or voltage divider) and fed to the input part of the filter, V_{iL}, then the output signal $V_{i'L}$ can be determined by transfer function of the BPF as shown belows :-

$$v_{i'_L} = \frac{k\tau_1 s v_{i_L}}{\tau_1\tau_2 s^2 + k\tau_1 s + 1} \tag{11}$$

where $k = g_3/g_2$

$\tau_1 = C_1/g_2$

$$\tau_2 = C_2/g_2 \tag{12}$$

B. OTA-Based Phase Comparator

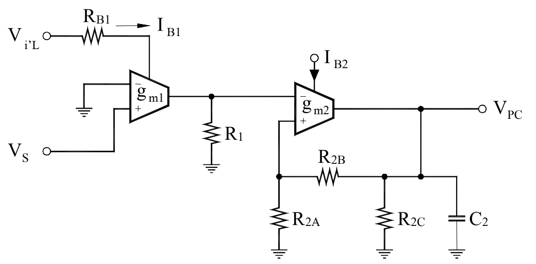

Fig. 3 OTA-Based Phase Comparator

OTA – multiplier and low pass filter circuit that shown in Fig. 3 is selected to defind the phase difference of the voltage source and output signal from band pass filter circuit

C. OTA-Based Phase shifter

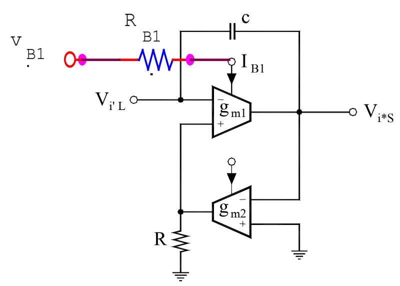

Fig.4 OTA-Based Phase shifter

Fig. 4 shows the OTA-Based Phase shifter using 2 OTAs to give the output signal that in phase with the v_S

The transfer function of OTA circuit is shown below: -

$$\frac{V_{i*S}}{V_{i'L}} = \frac{sc - g_{m1}}{sc + g_{m1} g_{m2} R} \tag{13}$$

$$If \quad g_{m2}R = 1 \tag{14}$$

The value g_{m1} will be automatic adjusted according to the bias current I_{B1} that corresponding to the phase difference output from phase comparator circuit.

D. OTA –Based Comparator

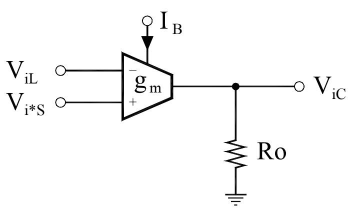

Fig. 5 OTA-Based Comparator

Comparator voltage signal can be determined by the OTA-Comparator circuit as shown in Fig.5.

E. OTA –Based Oscillator (Clock)

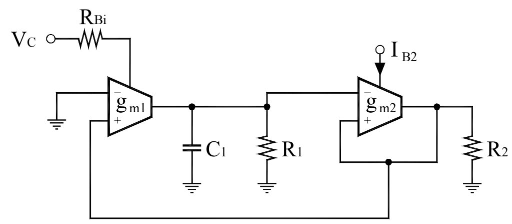

Fig.6 OTA-Based Oscillator

Clock to be used for modulation is designed by using OTA-Based oscillator as shown in Fig.6.

F. OTA – Based Pulse Width Modulator (PWM)

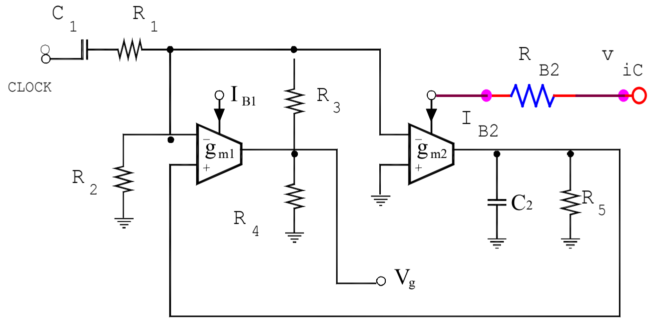

Fig.7 OTA-Based PWM

Fig. 7 shows the PWM using 2 OTAs to give the output signal to control the gate driver of the APF.

Modulation output signal will be automatic adjusted according to the bias current I_{B2} that corresponding to the output signal from OTA- Based comparator circuit.

IV. SIMULATION RESULTS

Simulation by ORCAD 9.1 using OTA LM13700 results shown in fig.8-12 . The harmonics of non-linear load is eliminated by compensation current from APF is shown clearly in Fig. 12.

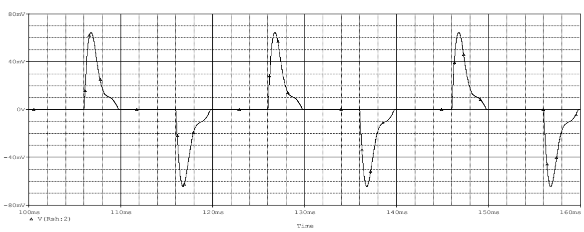

Fig.8 High THD non-linear load current characteristic

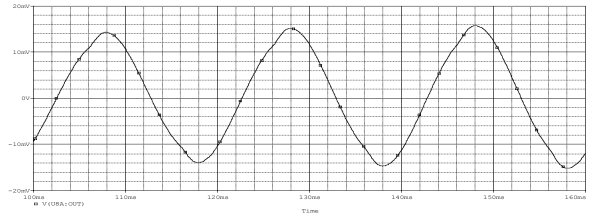

Fig.9 50 Hz Band Pass Filter output signal characteristic

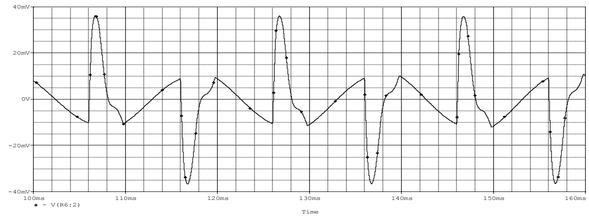

Fig.10 Compensation current characteristic

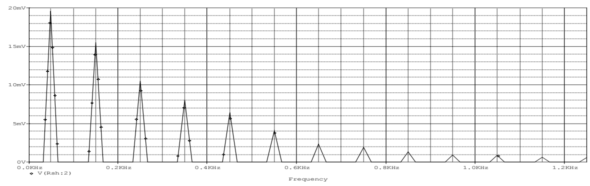

Fig.11 Frequency response of load current of an uncontrolled nonlinear load (THD 128%)

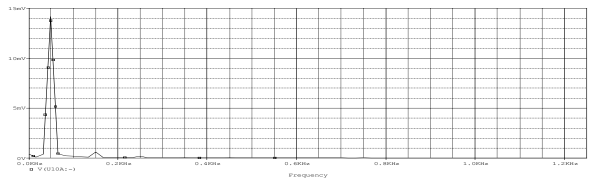

Fig.12 Frequency response of load current after compensation.

V. SUMMARY

In this paper, OTA circuits are developed for the control block diagram of the active power filter for harmonic and reactive power compensation.

The advantage of using OTA is to make the self-tuning for the control functions of phase shifter, phase comparator and PWM. OTA circuit can also be fabricated into one chip by CMOS technology which make low cost, simple and small size circuitry for the control system.

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