Power factor correction circuit for low-cost electronic ballast using current-source type push-pull resonant inverter

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A new low-cost high power factor correction circuit for electronic ballast employing current-source type push-pull resonant inverter (CS-PPRI) is proposed. The proposed circuit provides good power factor correction, low current harmonic distortion and cost-effectiveness. The prototype meets the IEC555-2 requirements satisfactorily.

Introduction: With the adoption of standards such as IEC555-2, there is a need to develop electronic ballasts for fluorescent lamps which can perform line current harmonic reduction and high input power factor correction (PFC). Among various filtering techniques, the active power factor corrector with a boost converter has been proven to be effective [1–3]. The boost-type PFC circuit is one of the most popular configurations due to advantages such as low ripple and good regulation of DC-link voltage, low flickering, etc. Nevertheless, the boost converter circuits lead to higher circuit complexity and thus higher product cost. In an attempt to search for a lower cost and less complex solution, cost-effective electronic ballasts with high power factor have been proposed [1–3]. When discharge lamps, such as fluorescent lamps, have to be driven in parallel with more than two connected, a current source rather than a voltage source drive is more suitable, and a new low-cost high PFC circuit for current-source type electronic ballast is needed.

In this Letter, a new power factor corrector combined with a charge-pumping capacitor pair [1] and CS-PPRI [3] is presented. This power factor corrector is capable of drawing high quality current waveform from an AC power line by inserting a pair of capacitors connected to the inverter and two DC-capacitors combined with secondary-side of current transformer.

Proposed power factor corrector: Fig. 1 shows the electronic ballast with the proposed high PFC circuit which is composed of a pair of charge-pumping capacitors (Cp1, Cp2) [1], two-level DC-link capacitors (Cdc1, Cdc2), a current-shaping diode pair and a self-excited current-source push-pull resonant inverter. The current-sourcing push-pull resonant inverter (CS-PPRI) is useful as a driver for low- and high-pressure discharge lamps which need to be fed by a current source. The proposed PFC circuit helps the self-excited CS-PPRI to correct the input current waveform by combining the inverter stage with a DC-link composed of only passive elements, which results in low-cost electronic ballast. In contrast to the PFC operation of the electronic ballast in [1], the proposed circuit in this Letter has almost constant; DC-link voltage, resulting in nearly constant lamp voltage magnitude and current waveforms.

The operations of the proposed PFC circuit can be explained by dividing the ranges of source line voltage into three parts. When the line voltage is low to nearly zero, sufficient current must be drawn from the line to supply the power to the DC-link stage as well as the inverter stage, which results in a steep line current waveform. If the line voltage is lower than the voltage of capacitor Cdc2, which is nearly half the line peak voltage, the charge pump-
Realisation of R-L and C-D immittances using single FTFN

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New resistor-inductor and capacitor-frequency-dependent negative resistance configurations are presented that use one plus-type four-terminal floating nullor (FTFN) and three passive components. The values of simulated elements can be orthogonally adjusted without any matching condition. Simulated results agree well with theoretical values.

Introduction: Current-mode circuits have received considerable attention because of their potential advantages [1, 2]. By using active current-mode elements, several circuits for realising series and parallel immittance functions have been reported [3, 4]. Recently, attention has concentrated on the use of the four-terminal floating nullor (FTFN) as an active current-mode element due to its greater flexibility compared to a current conveyor [4-6]. In this Letter, we present the realisation of parallel and series R-L and C-D immittance, along with parallel and series (-R)-(-L) and (-C)-(-D) immittance by using a single FTFN and only three passive components. The negative elements can provide circuit cancellation of the unavoidable positive elements. Filter circuits have been constructed to verify the theoretical analysis.

Fig. 1 FTFN model and implementation

a Nullor model of FTFN
b Plus-type FTFN implementation using AD844s

Circuit description: An FTFN is equivalent to an ideal nullor or is called an operational floating amplifier [6, 7]. The port relations of an FTFN, as shown in Fig. 1a, can be characterised as $I_0 = 0$, $I_2 = 0$, $V_1 = V_r$, and $I_r = \pm I$. The '+' and '-' signs of the $I_r$ denote plus- and minus-type FTFNs, respectively. Analysis of the circuit proposed in Fig. 2a yields the input admittance $Y_e = (L/V_w)$ expressed as

$$Y_e = \frac{I_1}{V_{in}} = 2y_1 + y_2y_4$$

If the admittances are $y_1 = 1/R_1$, $y_2 = 1/R_2$, and $y_4 = sC_0$, an R-L parallel immittance function $Y(s)$ can be realised, and it is given by

$$Y_{in}(s) = \frac{2}{R_1} + \frac{1}{sC_0R_2}$$

Applying the RC-CR transformation to the circuit in Fig. 2a, we can obtain a C-D parallel immittance function $Y_{in}(s)$. It is given by

$$Y_{in}(s) = 2sC_1 + \frac{2}{sC_1C_2R_3}$$

The second proposed circuit is shown in Fig. 2b. By using similar circuit analysis, the input impedance $Z_n = V_{in}/I_{in}$ can be expressed as

$$Z_n = \frac{V_{in}}{I_{in}} = \frac{1}{sC_1} + \frac{1}{sC_2} + \frac{2}{sC_1C_2R_3}$$

Similarly, if the impedances are $z_1 = R_1$, $z_2 = R_2$, and $z_3 = 1/sC_0$, an R-L series immittance function $Z_{in}(s)$ can be given by

$$Z_{in}(s) = R_1 + R_2 + 2sR_1R_2C_0$$

Applying the RC-CR transformation to the above circuit, a C-D series immittance function $Z_{in}(s)$ can be realised, where

$$Z_{in}(s) = \frac{1}{sC_1} + \frac{1}{sC_2} + \frac{2}{sC_1C_2R_3}$$

Since the negative immittance simulators can be used to provide circuit cancellation or reduce the values of the unavoidable positive elements [8], we present another two circuits to realise the parallel and series connections of (-R)-(-L) and (-C)-(-D). The FTFN is still used as an active element to demonstrate its flexibility. Considering the circuits in Fig. 3, the input admittance $Y_n$ in Fig. 3a and input impedance $Z_{in}$ in Fig. 3b can be expressed as

$$Y_n = \frac{I_{in}}{V_{in}} = -y_1 - \frac{2y_1y_2}{y_3}$$

$$Z_{in} = \frac{V_{in}}{I_{in}} = -z_1 - \frac{2z_1z_2}{z_3}$$

Similarly, by suitable selection of the imittance of passive components, parallel and series connections of (-R)-(-L) can be realised. After applying the RC-CR transformation to these two circuits, we can obtain a (-C)-(-D) parallel and series immittances. Note that the immittance values of the proposed circuits in [2, 3], which use a single plus-type FTFN and only three passive components, can be orthogonally adjusted without the need for matching components.

Simulation results: To verify the theoretical analyses, we use two AD844 operational amplifiers to implement a plus-type FTFN, as shown in Fig. 1b. All four proposed circuits are found to work, by simulation, when they have been used to construct filters. Consider the (-R)-(-L) parallel immittance in Fig. 3a. A two-order voltage-mode highpass filter can be realised by inserting a negative