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POWER FACTOR CORRECTION ALGORITHM IN AC-DC CONVERTER

Key words

The power factor, power factor correction PFC, AC-DC converter.

Summary

Power factor is a measure of the energy efficiency of the unit and corresponding losses in the transmission of electricity. Its value depends on the phase shift between voltage and current and the harmonic content of the supply current. In order to correct power factor circuits, the relevant passive or active circuits are used. This paper describes the algorithm for active power factor correction PFC control circuit AC-DC converter in the configuration step-up (boost) with continuous conduction current with the PWM modulation 20 kHz frequency. The results of studies of the dynamics of the converter are presented.

Introduction

Power factor PF is a measure of the use of the electricity consumed by the equipment supplied from the power grid. It is defined as the ratio of active power P to complex power S. A power factor of less than 1 means that it is possible to transmit the energy that is not used in full at the receiver [1, 2]. This is due to the reactive power Q flow between the power grid and the receivers containing capacitive and inductive components or non-linear receivers (e.g. power supplies). Power factor PF should not be confused with the cosine of φ.

Concepts cosine φ is used only when the current drawn by the power receiver is not in phase with the mains voltage, but both are sinusoidal signals (for example, when powered by electric motors). In this case, to correct the phase shift between current and voltage, special capacitor compensating inductive component of the load impedance is sufficient.

The main components of the non-linear receiver input stage are usually a rectifier and filter capacitor. The shape of supply current is in the shape of narrow pulses of high value. These pulses may be in phase with the voltage but do not have a sinusoidal shape. The flowing current is very deformed and characterized by a high content of harmonics [3]. The emission to the power grid harmonics will result in the following:

– Overload of the power grid caused by the increase in the effective value of the current,
– Overload of neutral conductors due to the summation of the third harmonics caused by single-phase receivers, and
– Deformation of the mains voltage, which negatively affects other devices connected to it.

The requirements for the content of harmonic current presented by the electrical power from the public grid are specified in PN-EN 61000-3-2 and EN 61000-3-12. They show that electrical power of more than 75W with CE marking must have a power factor correction PFC. These systems are divided into passive and active.

1. Passive Power Factor correction

In passive systems, as a part of compensation, a coil is used most often, located in front of or behind the bridge rectifier, along with serial and parallel filters of harmonics. The advantages of this method are simplicity, reliability, no emission of electromagnetic interference, and no switching losses. The main drawbacks of such systems are, in turn, weight and dimensions, in particular, in the case of power grid frequency filters, and the dependence of the waveform of the input current of the load. Moreover, despite the elimination of harmonics, the basic component can be relatively moved in relation to the voltage, thus lowering the value of the coefficient. As a result, the effectiveness of the passive power factor correction is smaller than the active correction and is dependent on load variations.

2. Active Power Factor correction

An active power correction circuit is a power supply, which, with a load impedance of any kind, linear or non-linear, the resistive load goes from the power grid. The construction of an active correction system is more complicated and requires the use of specialized integrated circuits and microcontrollers. Active power factor correction systems are used AC-DC converters connected in series with the load or with another component of the power supply, for example, the second step conversion of DC-DC and DC-AC [5–8].

Active power factor correction is switched on and off using a single transistor or transistors in a bridge configuration. For smaller power, MOSFET transistors are used, and for larger capacity, IGBTs are used.

One-transistor AC-DC converters with PFC function are usually built in the following configurations:

- step-down (Buck),
- step-up (Boost), and
- step-up/down (Buck-Boost).

The most widely used system is a step-up (boost). A characteristic feature of the inverter AC-DC working to set up a step-up is higher than the value of the DC output voltage than the maximum AC input voltage.

Because of the way the conduction current through the inductance of the equalizer PFC, the following methods are used:

- CCM – continuous conduction mode,
- DCM – discontinuous conduction mode,
- CRM – critical conduction mode,
- BCM – boundary conduction mode, and
- TM – transition mode.

When controlling a continuous flow of current, a typical PWM switching frequency fixed or variable hysteresis method of switching frequency is used.

3. AC-DC converter with active Power Factor correction PFC

ITeE – PIB's engineers, who developed and manufactured a high-power switching power supply for plasma surface treatment, used passive power factor correction circuits, and designed a unique system of correction [4]. The AC-DC converter with microprocessor control creates this system, which can be used with a DC-DC and DC-AC power source. Figure 1 shows a block diagram of a converter module made AC-DC with active power factor correction made in the topology step-up from continuous conduction current (CCM). This system consists of a coil L, switch transistor T, the diode D, and a capacitor C2. At its input, voltage supplied by the rectifier and filter capacitor C1 is rectified. At the output of adjustable voltage, UDC is obtained. The behaviour of a sinusoidal AC current consumption and phase according to the mains voltage is appropriate, with pulse switching on-and-off of the transistor T with a fixed 20 kHz frequency and variable pulse width.

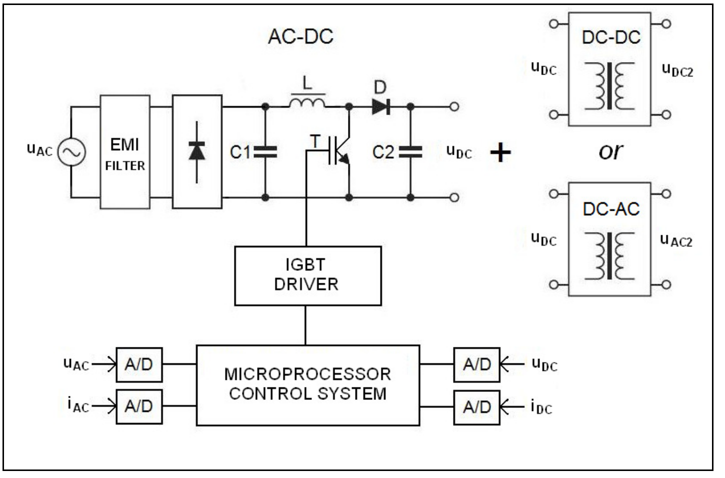

Fig. 1. Block diagram of the AC-DC converter with power factor correction PFC

The transistor T is controlled by a signal pulse width modulated (PWM) with an IGBT driver with a microprocessor control system. The implemented algorithm in the microprocessor power factor correction PFC calculates the pulse duration control based on the measured current and voltage values.

4. Power factor correction PFC algorithm

The algorithm of power factor correction (PFC) performed by the microprocessor control transistor T is shown in Figure 2. The implementation of the control algorithm was applied using microchip SH7084 of the Renesas Company. It has a 32-bit RISC architecture, internal Flash ROM memory with a capacity of 512 KB, an internal RAM data memory capacity of 32 MB and comes with a number of peripheral devices, including an extensive, multi-channel time-counter unit (MTU). This unit allows the generatation of the corresponding output signal microprocessor frequency and the preset conditions that were used to control the transistor mode pulse width modulation (PWM). This microcontroller is also equipped with 8-channel analogue-to-digital converter A/D, but due to insufficient resolution and processing speed, the external 12-bit AD7864 converter from Analogue Devices was used for measurement. This converter also controlled by the microprocessor, measures the instantaneous voltage u_{AC} current i_{AC} (it is also the current consumption of the power grid and the current flowing through the coil L), and output voltage u_{DC}.

The measurement is taken at 50 µs, which is half the course of the 200th voltage measurements. Main's voltage u_{AC} is a sinusoidal pattern for current i_{AC}. The voltage corresponding to the instantaneous current i_{AC} after analogue-to-digital conversion is subtracted from the reference voltage u_{REF}. u_{REF} voltage is the sum of the voltage u_{AC} multiplied by the factor A and the voltage amplitude U_0. U_0 voltage is constant and has been chosen empirically, and it is a constant component of the voltage u_{REF} and is necessary for proper generation of sine wave around zero voltage. The calculated error signal is amplified 10 times, and it is then subtracted from the signal u_{REF}, giving a value of modulation voltage u_{MOD}. u_{MOD} is directly proportional to the pulse width control; the higher the calculated value of the voltage, the greater the fill above a certain value u_{MOD}, and the pulse width is maximized. Amplitude factor A is determined in the "hysteresis regulator," based on the measured values of current i_{AC} and output voltage u_{DC}. It can be in the range 0 to 1. Depending on the value of the load resistance, to preserve a specified value of the output voltage u_{DC}, the amplitude of the current i_{AC} must change. To dynamically change the load, current i_{DC} did not affect the shape of the current i_{AC}, and thus the content of the harmonics; the hysteresis change of the output voltage u_{DC} to initiate change in the amplitude of the current i_{AC} and i_{AC} current amplitude change in the zero point was introduced. Microprocessor control of the AC-DC converter, apart from the fast control loop, performed at 50 μs, also performs other tasks. After the power is on, the microcontroller first performs tasks related to the initialization of digital inputs and outputs, the configuration of embedded peripherals (PWM channels, timers), and the initialization of internal interrupts from the timer and external to the corresponding input, the LCD initialization, and reads the settings from EEPROM memory. These tasks are executed once after each power-up, and after a reboot of hardware or software of the internal control system continuity program execution (watchdog) microprocessor. Then tasks are executed periodically in the main loop of the program, which include maintenance tasks inputs and outputs, analogue low-frequency measurements, and calculated moving averages of individual measurements of n measurement cycles. This loop reads the data entered by the user via the keypad or remotely via Modbus RTU communication interface.

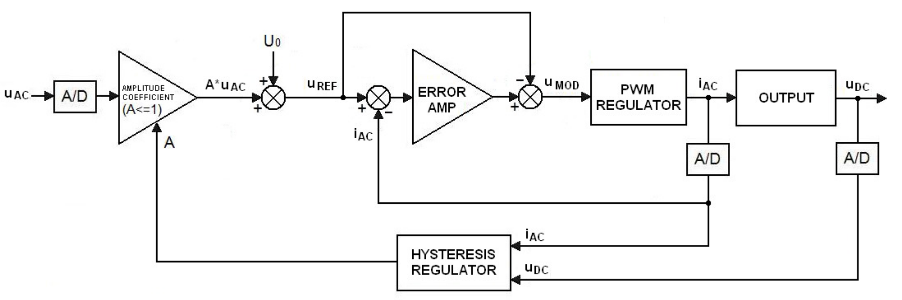

Fig. 2. Power factor correction (PFC) algorithm

During the performance of the tasks of the main loop, interrupt request of performance of the main loop through the internal timer chip is generated every 50 μs. The priority of this interrupt is set to the highest level. Interrupt request results in interrupt service routine (ISR), which means in this case, the algorithm performance power factor correction PFC.

5. Verification research of power factor correction algorithm of microprocessor control system

The AC-DC converter with designed power factor correction algorithm was built into the power magnetron plasma source 3 kW, and then it was tested on the bench experimental verification. The study focused on the correctness of the generated current, waveform compliance with the current phase voltage, and response of the inverter during start up and load changes.

The waveforms in Figure 3 show that the phase shift between current and voltage is negligibly small, and that the shape of the current waveform generated covers almost the entire half-line voltage. Delicate current waveform distortion at the beginning half period (Fig. 4) is due to the natural properties of the inductance, that is the response delay of current in enforcing voltage, and it is called *Cusp Distortion* [9]. This phenomenon cannot be completely eliminated, but it can be minimized by using a coil with lower inductance alues, but the side effect is, in turn, a higher value of ripple current di/dt. Ripple current, which are visible on the oscillogram (Fig. 4), have a frequency of

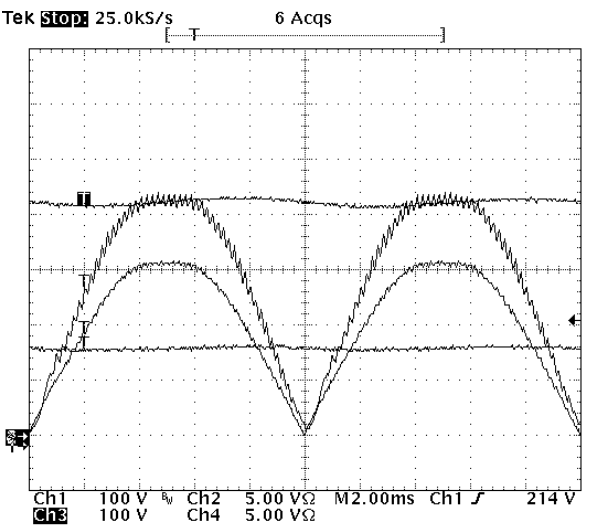

Fig. 3. Waveforms of currents and voltages in AC-DC converter (Ch1 – u_{AC}, Ch2 – i_{AC}, Ch3 – u_{DC}, Ch4 – i_{DC})

20 kHz and are produced during the switching by the transistor. The minimization of ripple at low inductance can be achieved by increasing the modulation frequency, but it requires the use of transistor T (Fig. 1), and may operate at frequencies above 20 kHz, and a faster microprocessor.

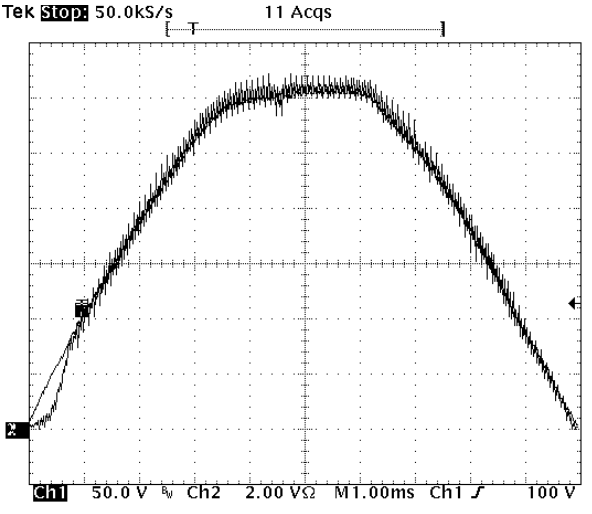

Fig. 4. Comparison of the shape of the voltage and current (Ch1 – u_{AC}, Ch2 – i_{AC})

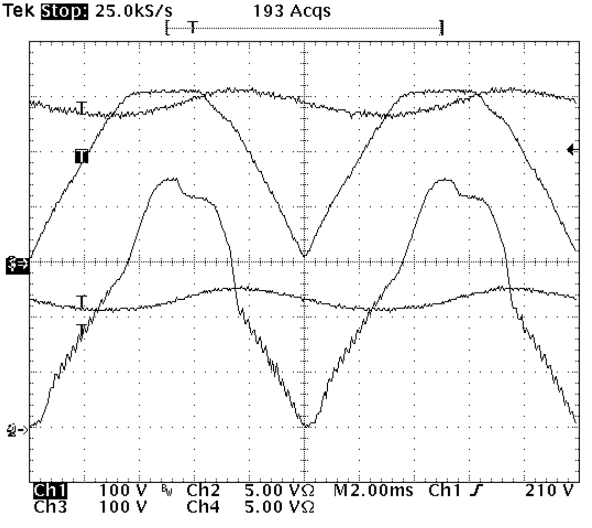

Fig. 5. Voltage 230 V, 25 Ω load, overload. When the instantaneous value of the u_{DC} is less than the maximum u_{AC} at the time of a typical phenomenon of temporarily straightening as in the current system without PFC (Ch1 – u_{AC}, Ch2 – i_{AC}, Ch3 – u_{DC}, Ch4 – i_{DC})

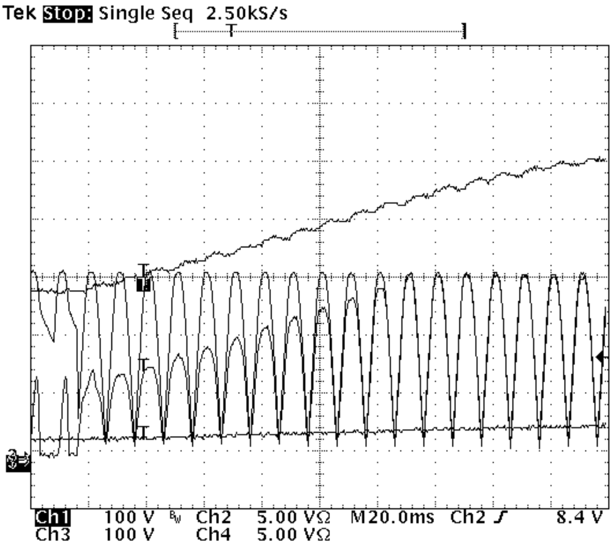

Fig. 6. Voltage 230 V_{AC}, switching the converter to operate at a load of 200 Ω, i_{AC} current amplitude change occurs in the zero point (Ch1 – u_{AC}, Ch2 – i_{AC}, Ch3 – u_{DC}, Ch4 – i_{DC})

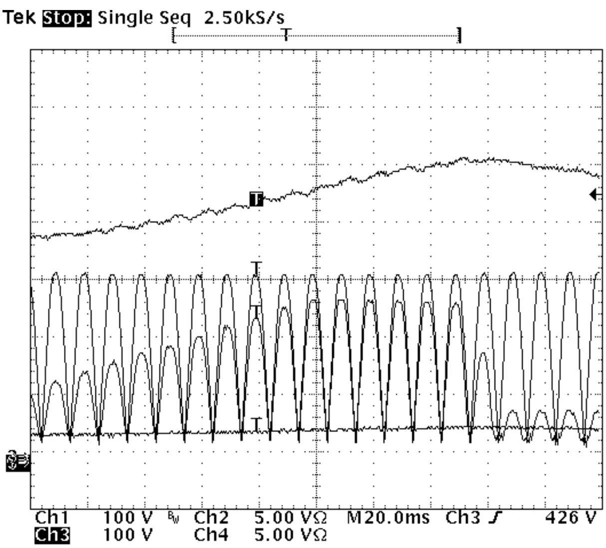

Fig. 7. Voltage 230 V_{AC} step change in output voltage of 400 V_{DC} to 500 V_{DC} with a load of 200 Ω, i_{AC} current amplitude change occurs in the zero point (Ch1 – u_{AC}, Ch2 – i_{AC}, Ch3 – u_{DC}, Ch4 – i_{DC})

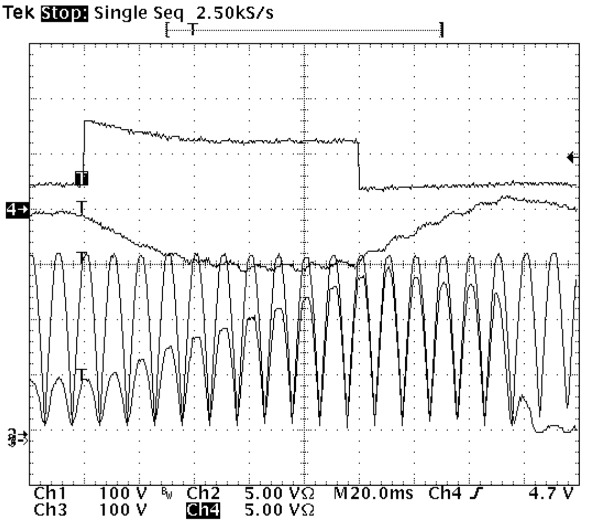

Fig. 8. Voltage 230 V_{AC} step change in load of 200 Ω to 50 Ω for the duration of 100 ms, i_{AC} current amplitude change occurs in the zero point (Ch1 – u_{AC}, Ch2 – i_{AC}, Ch3 – u_{DC}, Ch4 – i_{DC})

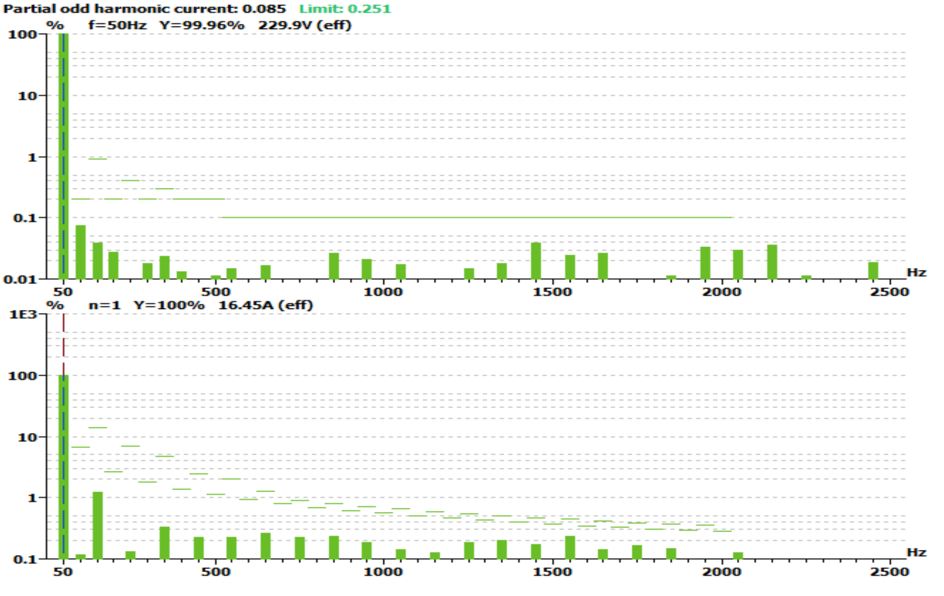

Fig. 9. Spectral graph of harmonic voltage (top) and input current (lower) with active PFC for current 16 $A_{RMS/AC}$

The research on the percentage of harmonic voltage and current AC-DC converter with active power factor correction were carried out using the source Netwave 7 (300 V_{AC}, 26 A_{AC}, frequency DC – 5 kHz, output power 7.5 kVA AC, DC output power 9 kW) and DPA500N harmonic analyser (up to 16A) of EM TEST. The content of each harmonics is less than 1% and the largest content is for the third component (around 1%), which is in accordance with DIN EN 61000-3-2 (Fig. 9).

Conclusions

The developed algorithm for power factor correction allows the control of a single-phase AC-DC converter in accordance with the requirements of the PN-EN 61000-3-2 for harmonic current emissions phase up to 16 A. This converter can be used with the next step conversion of DC-DC and DC-AC. It can be built into a device or can be a stand-alone power supply 3000 W with PFC function and a fixed regulated output voltage in the range 325 to 600 V. The use of a microprocessor allows the user to enter the operating parameters of the converter in a remote way (via serial RS485 Modbus RTU) or locally (using the LCD and keyboard), such as output voltage and the maximum current that can be drawn by the receiver.

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Algorytm korekcji współczynnika mocy PFC w przekształtniku AC-DC

Słowa kluczowe

Współczynnik mocy, korekcja współczynnika mocy PFC (*Power Factor Correction*), przekształtnik AC-DC.

Streszczenie

Współczynnik mocy PF (ang. *Power Factor*) jest miarą wykorzystania energii przez urządzenie i odpowiada stratom w przesyłaniu energii elektrycznej. Jego wartość zależy od przesunięcia fazowego między napięciem a prądem oraz zawartości składowych harmonicznych prądu pobieranego z sieci. W celu korekcji współczynnika mocy stosuje się odpowiednie układy bierne lub aktywne. W artykule opisano algorytm aktywnej korekcji współczynnika mocy PFC (ang. *Power Factor Correction*) w układzie sterowania przekształtnikiem AC-DC w konfiguracji step-up (Boost) z przewodzeniem ciągłym prądu z modulacją PWM o częstotliwości 20 kHz. Przedstawiono wyniki badań dynamiki przekształtnika.