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Research paper

Analysis of power factor corrections for obtaining improved power factors of switching mode power supply

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Abstract

This article discusses such an important issue as the power factor of Switching Mode Power Supply (SMPS) and its improvement through Power Factor Correction (PFC). The power factor shows how effectively uses the consumption of electric energy by certain loads connected to the power distribution system with Alternative Current (AC), which is very critical for the electricity-producing industry. The number of power factors is a dimensionless value that can vary from -1 to 1. Thus, in an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of transferring useful power, which may cause overloading of the power grid and lead to over-expenditure of electricity. Otherwise, designing power factor correction (PFC) into modern switched-mode power supplies (SMPS) has evolved over the past few years due to the introduction of many new controller integrated circuits (IC). Today, it is possible to design a variety of PFC circuits with different modes of operation, each with its own set of challenges. As the number of choices has increased, so has the complexity of making the choice and then executing the new design. In this article, the design considerations and details of operation for the most popular approaches are provided.

Keywords: *SMPS; PFC; PWM; MOSFET.*

1. Introduction

Power factor correction shapes the input current of off-line power supplies to maximize the real power available from the mains. In electronic engineering AC electrical loads are referred to either as linear or non-linear depending on how they draw current from the mains power supply waveform. Ideally, the electrical appliance should present a load that emulates a pure resistor, in which case the reactive power drawn by the device is zero. Inherent in this scenario is the absence of input current harmonics, when the current is a perfect replica of the input voltage (usually a sine wave) and is exactly in phase with it. In this case, the current drawn from the mains is at a minimum for the real power required to perform the needed work, and this minimizes losses and costs associated not only with the distribution of the power, but also with the generation of the power and the capital equipment involved in the process. The freedom from harmonics also minimizes interference with other devices being powered from the same source.

The circuits containing pure resistive heating elements such as cocking stove, iron, filament lamp and others similar have a power factor of 1. However, the circuits containing reactive elements (inductance or capacitors) such as solenoids, electric motors, lamp ballasts, and others have power factors below 1. The main property of linear load is that linear load doesn't distort power distribution system or in other words doesn't change wave shape of current in the power grid but only may change relative phase shifting between voltage and current. Such phase shifting can be simply compensated with the help of a parallel connection to a load of respective compensative reactive elements. The non-linear load is usually a rectifier, which widely used in industrial SMPS. The determination of non-linear load corresponds to circuits that use non-linear components such as semiconductors. The non-linear circuits used in SMPS have a power factor significantly below 1 and can be increased with the help of special PFC.

The types of linear load can be determined as resistive or reactive. With a linear load, the relationship between the voltage and current waveforms are sinusoidal and the current at any time is proportional to the voltage (Ohm's law). Examples of linear loads would include transformers, motors, and capacitors. Linear regulators are a great choice for powering very low powered devices or applications where the difference between the input and output is small. Even though they are easy to use, simple and cheap, a linear regulator is normally inefficient. The equation for dissipated power in a linear regulator is: Power dissipation = (input voltage – output voltage) × load current.

On the other hand, with a non-linear load, the current isn't proportional to the voltage and it fluctuates based on the alternating load impedance. Non-linear loads draw in currents in abrupt short pulses. These pulses distort the current waveforms, which in turn generate harmonics that can lead to power problems affecting both the distribution system equipment and the loads connected to it. Harmonics can cause problems such as distortion of the mains supply voltage, equipment overheating, nuisance tripping of circuit breakers, and misfiring of variable speed drives.

The non-linear load is usually a rectifier, which widely used in industrial SMPS. The determination of non-linear load corresponds to circuits that use non-linear components such as semiconductors. The non-linear circuits used in SMPS have a power factor significantly below 1 and can be increased with the help of special PFC. Common examples of non-linear loads include rectifiers, variable-speed drives, and electronic devices such as servers, computers and printers, peripherals, TV sets, customer electronics, telecommunication systems, and so on, that that is utilizing a Switched Mode Power Supply (SMPS) power conversion technologies.

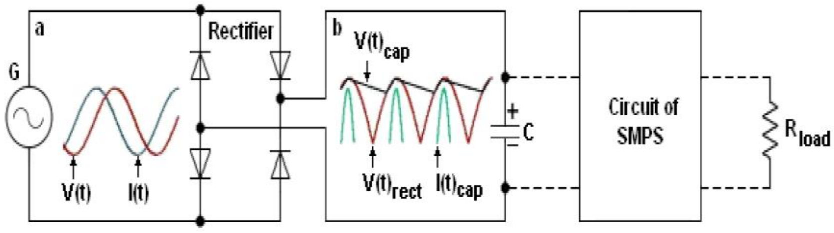

Fig. 1: Input Circuit of the SMPS.

2. Consideration of power factor for SMPS without PFC

Today a lot of devices such as desktop computers, laptops, monitors, TV sets and other devices comprise a Switching Mode Power Supply (SMPS), which is important to provide wanted voltage and current conditions for electronic circuit of certain device. The SPMS are rated with output power ranging from a few watts to more than 1kW.

The main part of SMPS circuits that causes reactive power is input circuit comprising diode rectifier and capacitor as shown in the Figure 1. At this point, if a circuit shows the higher produced reactive power, it is getting the lower power factor of the SMPS device. In Figure 1 shows input circuit of an SMPS with electrical processes, which occur in AC line (a) before the rectifier and in DC bus (b) after the rectifier. These electrical processes are illustrated below in more detail consideration, which makes clear cause of decreasing of power factor of SMPS circuit.

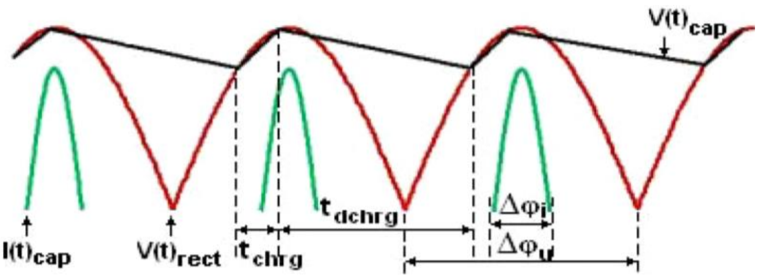

Fig. 2: Waveshape of fully Rectified Voltage $V(t)_{rect}$, Current $I(t)_{cap}$ and Voltage $V(t)_{cap}$ across input Capacitor (C).

The wave shape of fully rectified voltage $V(t)_{rect}$, voltage $V(t)_{cap}$ across capacitor C and current $I(t)_{cap}$ across input capacitor C are presented in Figure 2. The rectified voltage pulses $V(t)_{rect}$ after rectifier charge input capacitor C, what gives to these pulses more smooth wave shape $V(t)_{cap}$ and it becomes a DC voltage as illustrated in Figure 2. The current $I(t)_{cap}$ flows through rectifier during charging period t_{chrg} of the input capacitor C. It makes clear that phase of the charging current $I(t)_{cap}$ pulse $\Delta\varphi_i$ is shorter than the phase of rectified voltage $V(t)_{rect}$ pulse $\Delta\varphi_u$ and this phase difference produces phase shift $\Delta\varphi$ between voltage V(t) and current I(t) in the input AC line as illustrated in Figure 3.

The phase shift $\Delta\varphi$ between Voltage V(t) and Current I(t) in input AC line determines the power factor of the SMPS, so the bigger phase shift gives the lower power factor of the SMPS. Thus, to remove the phase shifting and thereby increase power factor of the SMPS can be used active or passive PFC circuits. Due to the different phase of voltage (V) and current (I), the burden of power supply line becomes heavier and the efficiency of power supply line is decreased, which requires that a capacitor should be connected to the AC electrical appliances to adjust the phase characteristics in voltage and current. The minimum voltage on the filter capacitor is far from zero, which is not much different from its maximum value (ripple peak).

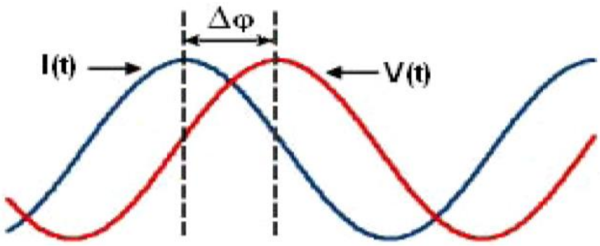

Fig. 3: Phase shift between Current I(t) and Voltages V(t) in AC Line before Rectifier.

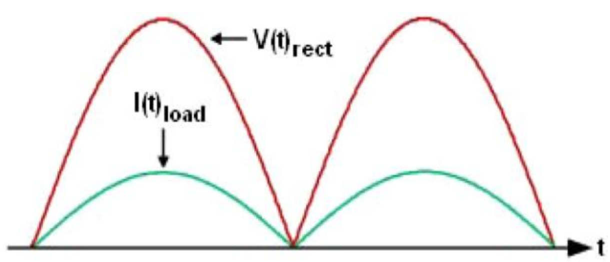

Fig. 4: Phase of Current $I(t)_{load}$ and Voltage $V(t)_{rect}$.

3. Characteristics of PFC and SMPS

There are two types of a PFC which can be used for SMPS such as active and passive one. A passive PFC usually represents low-pass filter which consists of capacitor and inductor connected, respectively. Such PFC can slightly suppress distortions and improve power factor as well. In fact, the passive PFC is not as useful as active PFC, because low efficiency causes, therefore it is not widely used for industrial SMPS [2]. Operation of the passive PFC is not considered in this article, due to simplicity and low applicability of it. Accordingly, only the active PFC is considered further.

Typically, a SMPS without any PFC has a power factor of only 0.55–0.65, but a SPMS with active PFC has a power factor significantly higher in range between 0.90-0.95 [3]. This point makes reasonable application to employ an active PFC for SMPS. An active PFC is a power electronic system which changes the phase of current drawn by a load to improve the power factor. The active PFC makes the circuit of SMPS as like a purely resistive, what helps to improve power factor of the SMPS up to possible maximum. The active PFC provides drawing of current $I(t)_{load}$ only in phase with rectified voltage $V(t)_{rect}$, as illustrated in Figure 4. In such a way, phase of Current $I(t)_{load}$ and Voltage $V(t)_{rect}$ are the same with applying of active PFC.

At this point, only previous stated characteristic enables the most efficient technique for delivery of electrical power from the power grid to the certain SMPS circuit. An electronic power circuit of active PFC as a circuit of boost topology is illustrated in Figure 5.

The circuit of the active PFC consists of diode rectifier, choke coil (L), Current Sensor (CS) embed in negative bus, active element VT, Diode (D0, required for boost circuit, output Capacitor (C), resistive voltage divider as Voltage Sensor (VS) of output voltage and PFC controller. The amplitude values of rectified voltage, current and output voltage come to the PFC controller, which provides permanent collecting and processing of these coming values. The PFC controller provides processing of these collected values to determine driving parameter for the active element VT or in other words determines time of turning on and turning off of the active element VT. The operation accuracy of the PFC controller defines the maximum possible efficiency of entire PFC circuit. The detail principal of operation of the PFC controller is considered below.

In same instances, the standard structure of the PFC controller is illustrated in Figure 5. However, one important thing which watches the PFC controller is not to allow flowing of any current across choke coil (L) when amplitude of the rectified voltage is equal to zero and exceed value of the current across choke coil (L) proportional to certain actual amplitude of the rectified voltage.

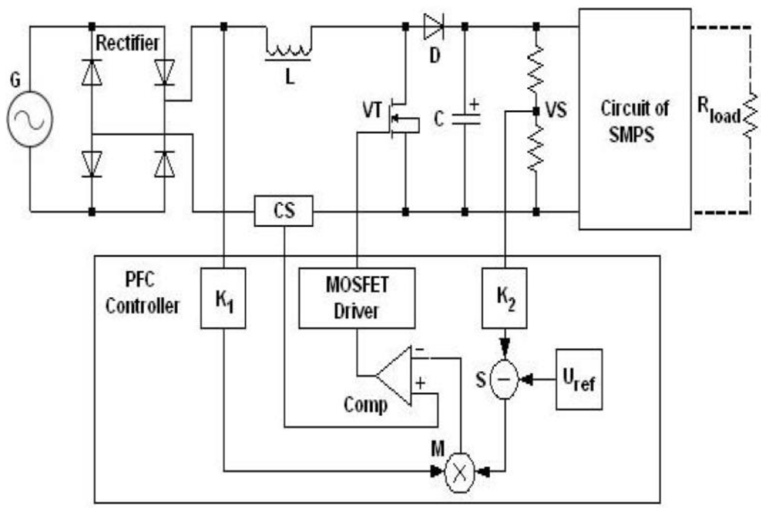

Fig. 5: Simplified Electronic Power Circuit of the Active PFC.

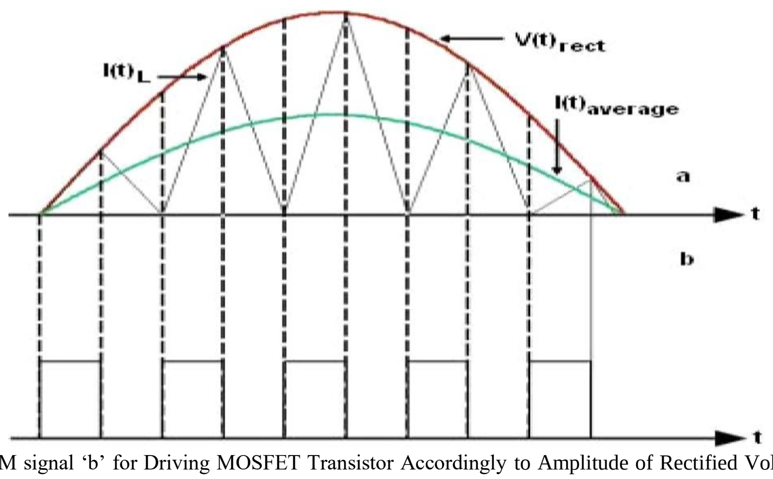

Fig. 6: Timing Diagram of PWM signal 'b' for Driving MOSFET Transistor Accordingly to Amplitude of Rectified Voltage $V(t)_{rect}$ and Current Across Choke Coil $I(t)_L$ 'a'.

It is ensured by the PFC controller in following way: value of amplitude of the rectified voltage comes to Multiplier (M) trough attenuator (K_1) and at same time supports constant value of output voltage, and then value of the output voltage from voltage divider (VS) comes to Multiplier (M) through subtractor (S) and attenuator (K_2) as well. The result of multiplying goes to inverting input of Comparator (Comp) and value of the current comes to non-inverting input of the Comparator (Comp). The result of comparison comes to Metal Oxide Silicon Field Effect Transistor (MOSFET) driver unit which provides formation of driving Pulse Width Modulation (PWM) signal for MOSFET transistor. Usually can be used other types of transistors, however in our case for consideration is used MOSFET transistor, further for convenient description is used only word “transistor”.

The PWM driving signal for transistor is determined by two factors such as value of amplitude of the rectified voltage and the current across choke coil (L) as shown illustrated in Figure 6. A PWM signal presents itself sequences of pulses with different value of duty-cycle or different pulse width. The every pulse of the PWM sequence simply means moment of turning on of a transistor with rising front of the pulses and turning off of a transistor with falling front of the pulses respectively.

As shown in Figure 6 the formation process of pulse for PWM signal or turning on of a transistor gets started when value of the rectified voltage $V(t)_{rect}$ is equal to zero and the current across choke coil (L) is equal to zero as well. Turning off of a transistor is occurred when value of the linearly increasing current $I(t)_L$ across choke coil (L) becomes equal to certain proportion of amplitude value of the rectified voltage $V(t)_{rect}$. After turning transistor off the current across choke coil (L) linearly decreasing and when value of the current becomes equal to zero transistors turning on over and over again, all this process is provided and controlled by the PFC controller with relatively high frequency. In such a way, it occurred active correction of power factor with help of an active PFC [4].

The current across choke coil $I(t)_L$ can be represented as integrated average current $I(t)_{average}$ across a choke coil and this current is the same current that drown by a load. The choke coil (L) is component that determines the total power of the active PFC circuit.

4. Conclusion

From considered material in the article should be concluded advantages and disadvantages of application an active PFC, so the advantages of the active PFC are as follows:

- High efficiency of power factor correction is around 0.90-0.95, what means that an active PFC almost doesn’t produce reactive power in AC line and minimizes level of non-linear distortions as well;
- Electrical efficiency of an active PFC itself is around 0.95;
- Can be used for any variety of a SMPS with different range of power consumption;
- An active PFC is more cost effective then higher desirable power for a SMPS.

The disadvantage of an active PFC is only complicated design of the power circuit of the active PFC.

The material presented in this article is essential for understanding how operates an active PFC. As continuing of this article will be ensured one more article with designed and implemented an active PFC circuit for applying with powerful SMPS, which will be based on the described material above.

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