BASIC TOPOLOGIES OF DIRECT PWM AC CHOPPERS

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Abstract – **In this paper some basic topologies of direct PWM AC choppers are presented. Compared with the phase-controlled AC controllers using thyristors the PWM AC Choppers have important advantages: sinusoidal current waveforms, better power factor, faster dynamics and smaller input/output filters. They present high robustness, offer safe commutation and have high efficiency. The paper describes operational principles and analysis of three basic direct topologies using a very simple DC snubber consisting of a capacitor only with no discharging resistors. This DC snubber is directly attached to power commutation cells to absorb energy stored in stray line inductances. There are also shown some modern line conditioners made up of basic PWM AC choppers and a transformer for series voltage compensation.**

Keywords: *direct AC-AC converter, direct PWM AC chopper, line conditioner*

1. INTRODUCTION

The recent increase in the use of nonlinear loads has caused serious concern for power quality and consequently on the disturbances tolerated by sensitive electronics loads. Currently, most of the line conditioners still rely on thyristor technology (line-commutated ac controllers). The absorbed harmonics current present high amplitudes and low frequencies. Due to the emplacement of these harmonics near the fundamental harmonic at the power supply system it is not recommended to use passive filters. Also the size, weight and price of the passive elements could be high. Therefore, direct AC-AC converters with thyristors are placed outside of new electromagnetic compatibility (CEM) standards that limit the admitted perturbations in the power supply system [1]. More, the reactive power absorbed by these converters changes at the same time with the delay control angle. Such conditioners, however, have slow response and need large input-output filters to reduce low-order harmonics. Line-commutated AC controllers can be replaced by pulse width modulation (PWM) AC choppers, which have better overall performance and the above problems can be improved if these controllers are designed to operate in the chopping mode. In this case, the input voltage is chopped into segments and the output voltage level is decided by controlling the duty cycle of the chopper switching function.

Before the 90s, PWM AC choppers were made by four quadrants switches [2]-[4]. Their application was delayed due to the commutation problems. To assure safe commutation without high voltage spikes, some PWM control principles were developed [3]-[4]. However, converters robustness depended on the control accuracy and kept high the risk of overvoltages and overcurrents appearance.

After 1990, different AC choppers topologies using a reduce number of switches [5]-[6] or standard commutation cells in two quadrants [7] were developed. To increase the converters robustness simple DC snubbers consisting of a capacitor only attached directly to commutation cells were used [8]-[11].

In this paper some basic topologies of direct PWM AC choppers are comparatively studied (fig.1). These have numerous advantages, such as: quasi-sinusoidal current waveforms, better power factor, faster dynamics and smaller input/output filters. PWM AC choppers present high robustness, offer safe commutation and have high efficiency. The two basic AC topologies work similar with DC choppers, at a constant duty cycle, having a better dynamic and a large industrial use.

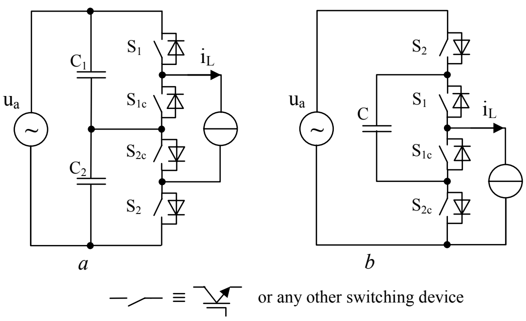

Fig.1 Basic single-phase AC PWM choppers:
a differential topology; *b* non-differential topology.

There are also shown some modern line conditioners made up of basic PWM AC choppers and a transformer for series voltage compensation.

2. BASIC PWM AC CHOPPERS

2.1. Single-phase topology

By the supply mode, PWM AC Choppers are classified in differential and non-differential topologies. Both structures are made by two inverter commutation cells with IGBTs bidirectional in current and unidirectional in voltage. DC snubbers are attached directly to commutation cells to absorb the energy stored in line stray inductance. These snubbers have a very simple structure, consisting of a capacitor only with no need for discharging resistors. In differential topology (fig.2*a*) the S_2 and S_1 switches, the voltage source and the load are serial connected. By moving S_2 switch between the voltage source and S_1 switch non-differential topology is obtained (fig.2*b*) [12]-[13]. This second structure presents the neutral wire continuity advantage.

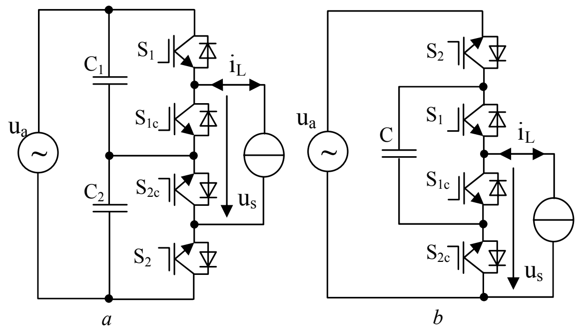

Fig.2 Basic single-phase PWM AC choppers, buck type: *a* differential topology; *b* non-differential topology.

Both converters have the same control, depending on the voltage source u_a sign. In this way, if u_a is positive, S_1 and S_{1c} switches are PWM controlled with a constant duty (α) ratio, while S_2 and S_{2c} switches are fully turned on (fig.3).

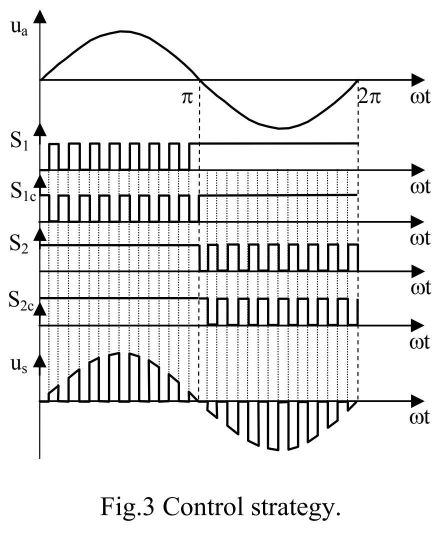

Fig.3 Control strategy.

When the sign of the voltage source is changed, the switching pattern is reversed, S_2 and S_{2c} being complementary PWM controlled with a constant duty ratio and S_1 and S_{1c} are fully turned on. In these switching patterns the current path always exits whatever the inductor current direction. Since two switches are always turned on during the half period of the voltage source the switching loss is significantly reduced. In the buck conversion topology the output voltage is proportional with the duty ratio:

$$u_s = \alpha \cdot u_a \tag{1}$$

During one switching cycle, basic PWM AC choppers present three possible operating modes: active mode, freewheeling mode and bypass mode.

Active mode

During this mode, the inductor current i_L conducts through input and output side and provides output energy. The S_1 and S_2 switches are turned on and the inductor current i_L conducts through S_1 and the diode across S_2 for $i_L>0$ or S_2 and the diode across S_1 for $i_L<0$, as shown in fig.4*a*.

Freewheeling mode

This mode is complementary to the active mode. During this mode the switches S_{1c} and S_{2c} are turned on so that the inductor current freewheels through the output side, as shown in fig.4*b*.

Bypass mode

The bypass mode is imposed by non-linear regime of power devices. To avoid commutation problems during dead time, a specific control strategy for this type of conversion was proposed [7]-[8]. Two additional switches are turned on for safe commutation in this mode. When the input voltage u_a is positive, the switches S_2 and S_{2c} are turned on for safe commutation. During the dead time the inductor current i_L conducts in the positive direction through the load, the S_{2c} switch and the diode across S_{1c}. The negative inductor current i_L conducts through the voltage source, the S_2 switch and the diode across S_1. Thus, a current path for the inductor current always exists in every current direction during the bypass mode. The current paths in this mode, for $u_a>0$, are shown in fig.4*c*. Table 1 presents the output voltage depending on the switches control. The main restrictions for this control are the accuracy and speed for detecting the voltage source sign.

2.2. Three-phase topology

Single-phase topologies structures can be extended for three-phase structures. We are interested only in the case of differential topology because of the number of commutation cells is two times smaller than the three-phase non-differential topology [7], [14]. By adding a third commutation cell to the single-phase topology, a differential three-phase PWM AC chopper is obtained (fig.5). A snubber made by only one capacitor is attached directly to each commutation cell. As in the single-phase topology, this structure presents the advantage of using standard commutation cells in two quadrants. The control can be realized by taking into account the current or the voltage source sign.

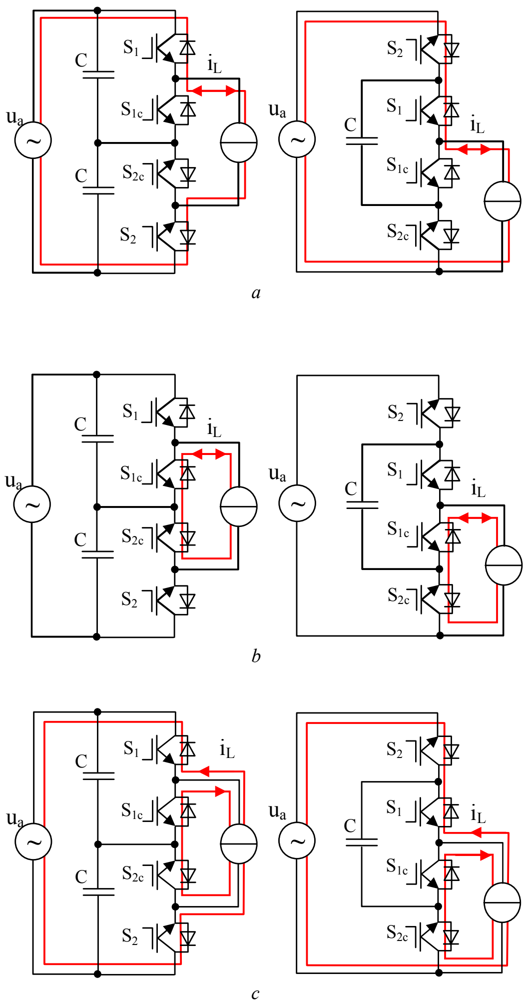

Fig.4 Current paths for operating modes: *a* active mode; *b* freewheeling mode; *c* bypass mode.

	S_1	S_{1c}	S_2	S_{2c}	u_s	
					$i_L>0$	$i_L<0$
$u_a>0$	1	0	1	1	u_a	u_a
	0	0	1	1	0	u_a
	0	1	1	1	0	0
$u_a<0$	1	1	1	0	u_a	u_a
	1	1	0	0	u_a	0
	1	1	0	1	0	0

Tab.1 Output voltage depending on control.

The first control, depending on the current's sing, is realized by having identical duty cycles. In this case only active and freewheeling operation modes are allowed. As a result, there is no indirect energy change similar to a bypass operating mode. Another disadvantage is to determine the current's sign near the passing through zero.

In the single-phase topology, the PWM AC chopper operates like a unidirectional voltage chopper. In the second control (depending on the voltage source sign) the three-phase structure operates like two independent unidirectional voltage choppers. It means that the duty cycles can be different, which is an important advantage in comparison with the previous control.

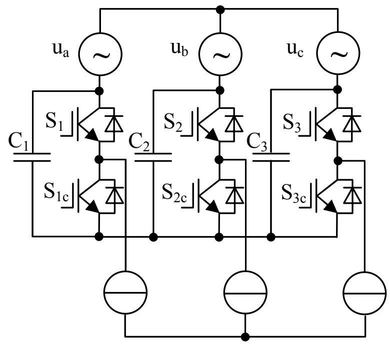

Fig.5 Three-phase differential AC chopper.

In the buck PWM AC chopper for three-phase systems, the switches with the smallest voltage source among three voltage sources are fully turned on. Other switches are modulated with a constant duty ratio. For example, if the voltage of phase *a* is the smallest, switches S_1 and S_{1c} are fully turned on, while S_2, S_{2c} and S_3, S_{3c} are complementary switched with a constant duty ratio. The operational modes are the same with the single-phase buck AC chopper: active mode (fig.6*a*), freewheeling mode (fig.6*b*) and bypass mode.

The imposed voltages across commutation cells are not sinusoidal, as shown in fig.7. For this reason, the currents through the snubber capacitors present important discontinuities. The capacitors size has to be small enough to limit their currents, so that the harmonic content does not influence the input filter.

3. MODERN LINE CONDITIONERS

Many factors, such as energy sources, supply lines and loads, disturb the distribution network voltage quality. The energy producer has to maintain at standard values the voltage amplitude and frequency. However, switching in voltage sources, natural phenomena (thunderbolts) or accidental phenomena (broken line) lead to modify the voltage quality, by generating important and unforeseeable disturbances. Also, high loads variations produce more or less local voltage source changes. The use of power electronic in industrial and household applications generates harmonic pollution to the power supply system: harmonic currents absorbed by the nonlinear loads modify the voltage through the input impedance.

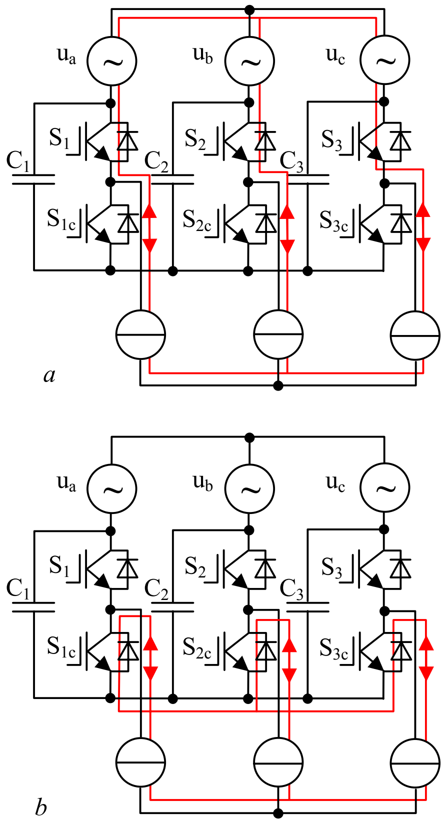

Fig.6 Operational modes for three-phase differential AC chopper, buck type: *a* active mode; *b* freewheeling mode.

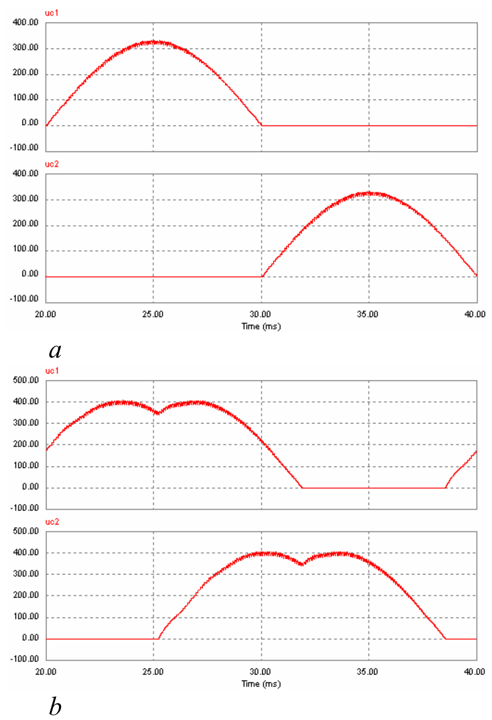

Fig.7 Cells 1 and 2 voltages: *a* single-phase PWM AC chopper; *b* three-phase PWM AC Chopper.

Line conditioners have been used in industry to provide and to protect sensitive loads. There is a large variety of line conditioners which absorb one or more types of disturbances, like line conditioners with or without energy storage. Line conditioners with energy storage, for example uninterruptible power supply (UPS), protect the equipments against a high number of disturbances, including short disconnections which are the most expensive. The line conditioner's without energy storage category includes compensators, which stabilize the voltage source by reactive power control and active filters. In the same category are included line conditioners made by basic AC choppers. They work at high commutation frequency and allow a fast and continue output voltage control. There are direct and indirect types of line conditioners without energy storage. In the direct type case one or more AC choppers are connected between the voltage source and the load (fig.8*a*). The indirect type is made up of a PWM AC chopper and a transformer for series voltage compensation (fig.8*b*).

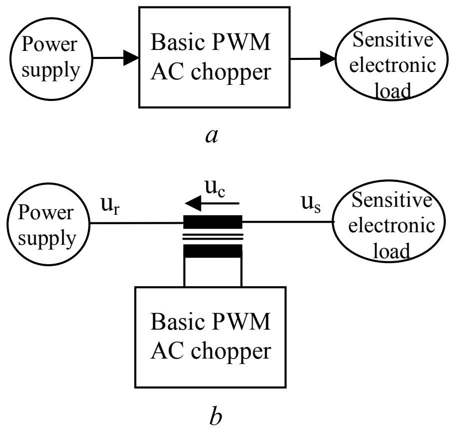

Fig.8 Modern line conditioners: *a* direct topology; *b* indirect topology.

In the case of direct line conditioners differential AC choppers topologies are preferred, while indirect line conditioners use differential or non-differential AC choppers topologies. The serial voltage (u_c) given by the transformer is controlled by AC chopper in order to compensate the voltage source fluctuations. As a result, a constant load voltage with the indirect line conditioner is obtained. The serial voltage (u_c) is only a small part of the voltage source, which allows the line conditioner to absorb a reduced power. The AC chopper output voltage is in phase with the voltage source. The relative sign between the primary and the secondary of the series transformer (indicated by blackened points) allows to increase or to decrease the voltage delivered to the load ($u_s = u_r + u_c$), depending on the connection mode (fig.9). To reduce the PWM AC chopper absorbed power the use of buck topologies is recommended.

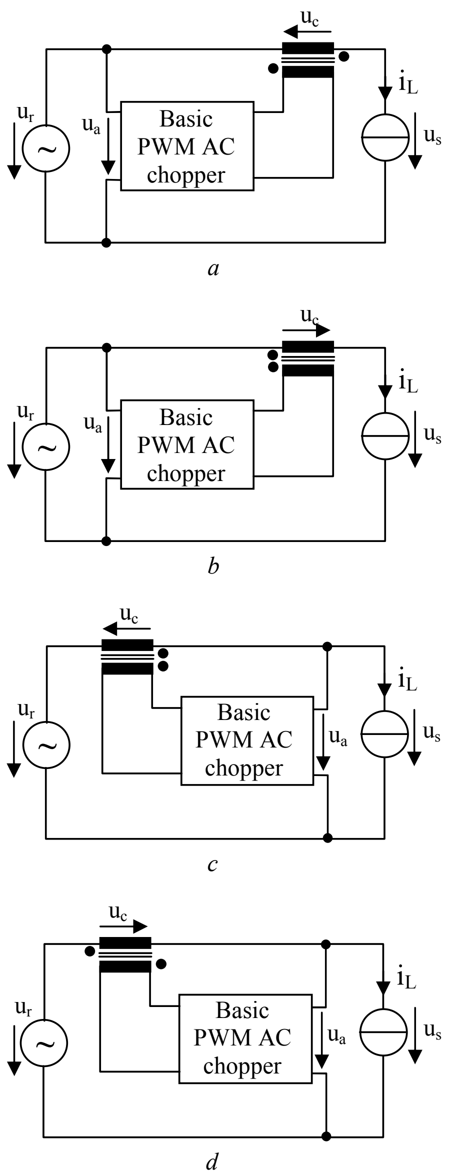

Fig.9 Line conditioners without energy storage:
a boost circuit with power supply from input side;
b buck circuit with power supply from input side;
c boost circuit with power supply from output side;
d buck circuit with power supply from output side.

To allow the compensation of voltage variations in both directions a serial boost line conditioner with a buck one are associated. There are many possibilities to associate basic AC choppers with serial transformers. Fig. 10 presents a line conditioner with voltage up/down capability made by two non-differential AC choppers [14]. The first structure delivers the voltage u_{s1}, which have an increase voltage effect, while the second one delivers the voltage u_{s2} with a decrease voltage effect. As a difference between the two previous voltages (u_{s1}, u_{s2}) a compensation voltage is obtained, which is serial injected through a transformer with the voltage source. The voltage delivered to the load can be obtained as a function of the voltage source u_r and the AC choppers input voltages (u_{a1}, u_{a2}) by taking into account their duty cycles (α_1, α_2):

$$u_s = u_r + m \cdot (\alpha_1 \cdot u_{a1} - \alpha_2 \cdot u_{a2}) \qquad (2)$$

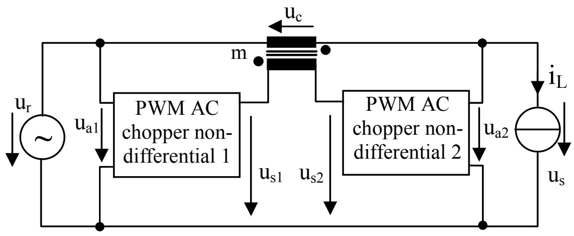

Fig.10 Line conditioner with voltage up/down capability.

4. CONCLUSIONS

In this paper basic PWM AC choppers made by two quadrants commutation cells were presented. The most simple control principle to implement is the one based on the voltage source sign. More, it no needs devices to limit the current, which reduce losses. Structures based on two quadrants commutation cells are more robust than other based on four segments switches. Their devices components have not commutation voltage spikes due to the simple snubbers attached directly to each commutation cell. The non-differential AC chopper has the same robstness like the differential one and more, it presents the advantage of neutral wire continuity. The three phase differential topology is made only by three commutation cells representing an important advantage.
In accordance with standard CEM, the phase controls must be replaced by modern structures like the ones presented in this paper. PWM AC choppers deliver quasi-sinusoidal voltages. As a result, these modern converters can be used in a bigger number of applications. At an equal apparent power a PWM AC chopper is more expensive than a transformer. In order to reduce the converter's apparent power and to increase the voltage supply quality the paper presented some modern line conditioners made up of basic PWM AC choppers.

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