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Power Factor Considerations for the Mid-Point Converter System

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Abstract: As the quest to counteract the undesirable effects of electric load which create power factors less than unity increases, a novel mid-point converter system is presented. This is a phase-controlled ac to dc converter where the conducting and switching method is on one-to-one basis, unlike the full-bridge converter whose switching goes in pairs. Using the fourier series, the generalized power factor of this system of converter was calculated. From this general power factors, the power factor of the mid-point converter with any number of phases and pulse numbers can be calculated.
Keywords: ac to dc converter, phase-control, power factor correction, fourier series, pulse numbers, conducting and switching, one-to-one basis.

INTRODUCTION

The growing demand for power, no doubt, increases in dimension on daily basis resulting in increased number of nonlinear loads in the utility system. This calls for urgent intervention to create awareness of various properties of converters to help practicing engineers in selecting appropriate ac to dc converters for various applications and uses in order to stem-down the tide. Again, with the increasing application of static switched converters for controlled industrial power supplies, the non-sinusoidal utility line current being drawn by these converters which essentially constitute the nonlinear load in the system has kept on increasing. The non-sinusoidal current contain harmonics which not only give rise to poor ac input power factor to the nonlinear loads but also constitute level of interference to the communication lines[1]. This level of interference called Electromagnetic Interference (EMI) increases with the concentration of units of nonlinear loads connected to the utility supply system in any given phase [2].

To guard against poor ac power factor which draws excessive reactive power from the system and to also limit the level of EMI, professional bodies such as Institute of Electrical Electronic Engineers (IEEE) etc, have specified limits of harmonic levels to be injected by nonlinear loads into the system, while utility companies often as a punishment to erring consumers, heavily charge customers for excessive reactive power being drawn from the utility supply [1].

In this paper, a novel mid-point converter system is presented. This is a phase-controlled ac to dc converter where the conducting and switching method is on one-to-one basis. That is to say, unlike the full bridge converter where the switching goes in pairs, it is single in the mid-point converter.

MID-POINT CONVERTER CONFIGURATION

As earlier mentioned, this is a phase-controlled ac to dc converter whose conducting and switching method is on one-to-one basis. Figures 2.1, 2.2 and 2.3 showed the different configurations of the mid-point converters system. In its features, there are as many phases as are the number of thyristors in the mid-point converter [2].

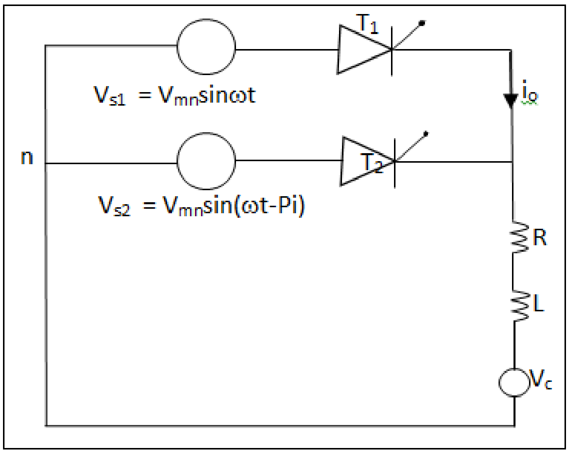


Fig-2.1: Two-phase (two-pulse) mid-point converter circuit

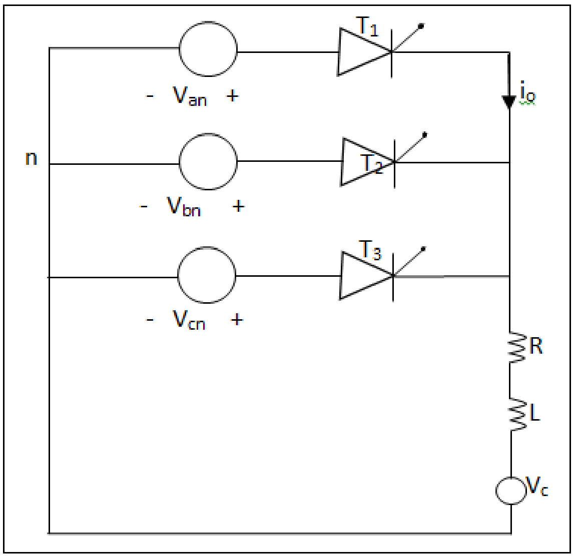


Fig-2.2: Three-phase (three-pulse) mid-point converter circuit

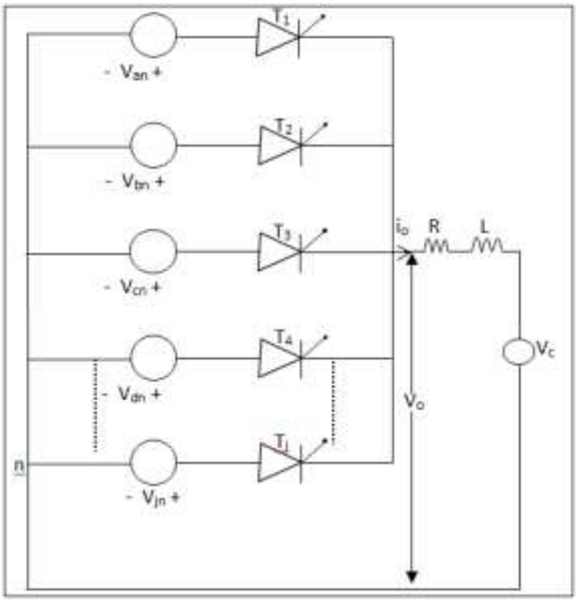


Fig-2.3: Generalized case of phase-controlled mid-point converter circuit

From figure 2.3:

$$\left.\begin{aligned} V_{cn} &= V_{mn}Sin\ \omega_t \\ V_{bn} &= V_{mn}Sin\left(\omega_t - \frac{2\pi}{Npm}\right) \\ V_{an} &= V_{mn}Sin\left(\omega_t - \frac{4\pi}{Npm}\right) \\ V_{jn} &= V_{mn}Sin\left(\omega_t - 2\pi\,\frac{(Nmn-1)}{Npm}\right) \end{aligned}\right\} \quad 2.1$$

Where Nmn is the number of pulse: 1, 2, 3, 4, …n

In Nmn pulse mid-point converter, the number of converter output pulse is Nmn with each pulse having an angular distance period of $\frac{2\pi}{Nmn}$ [3].

MID-POINT CONVERTER
POWER FACTOR

Mid-point converter has advantage over the two-pulse bridge converter because of its use in low-power applications e.g. in control of low voltage motors [2]. Here, the thyristor voltage drops and losses are halved compared to the two-pulse bridge converters. The mid-point converter poly-phase circuit is shown in figure-3.1 in which the number of thyristors represent the number of phases. The voltage and the corresponding fundamental current waveforms are shown in figure-3.2.

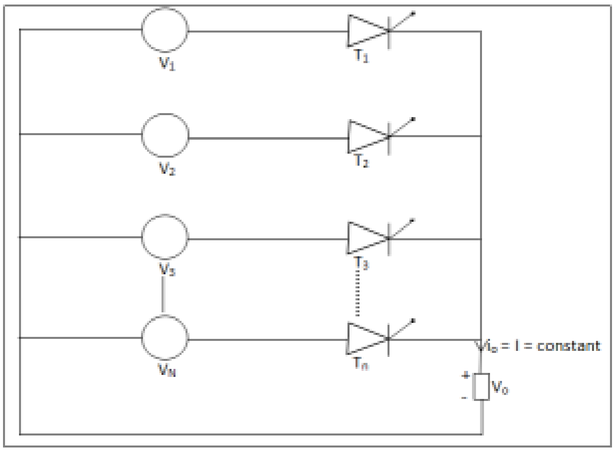
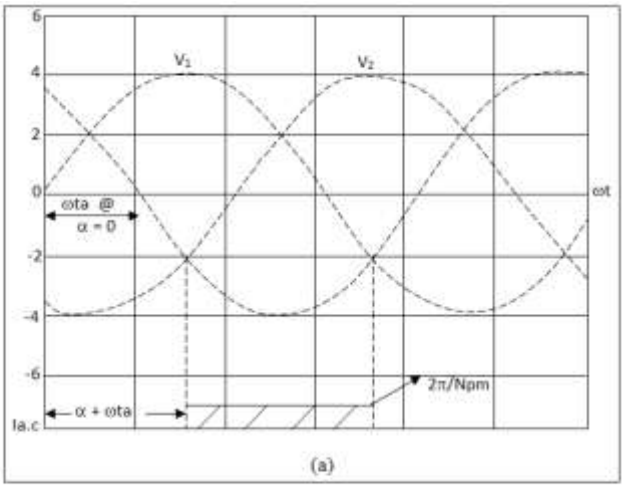


Fig-3.1: Generalized case of poly-phase controlled mid-point converte



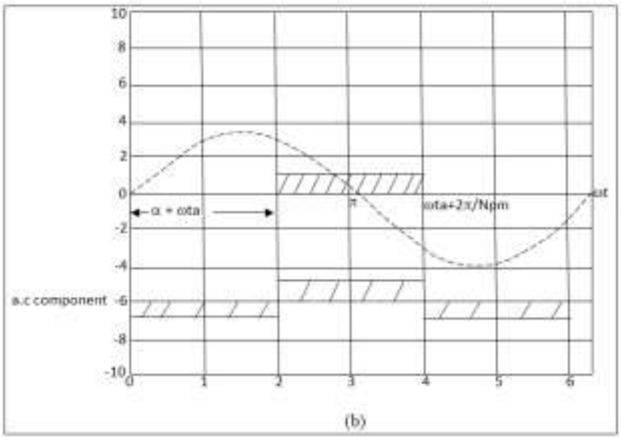


Fig-3.2: (a) The voltage waveform of the 3Φ mid-point converter (b) The fundamental current waveform

In this converter, only one thyristor conducts at a time. For instance, T_1 conducts in the positive half cycle while T_2 conducts in the negative half cycle and so on. For a three-phase mid-point converter, looking at v_1 (from the voltage waveform) and the ac component of current, and employing fourier series [3].

$$A_n = \left(\frac{2}{\pi}\right) \int_{\alpha+\omega+a}^{\alpha+\omega ta+\frac{2\pi}{Npm}} [Id\ Cos\ n\omega t]d\omega t ------3.1$$

$$B_n = \left(\frac{2}{\pi}\right) \int_{\alpha+\omega+a}^{\alpha+\omega ta+\frac{2\pi}{Npm}} [Id\ Sin\ n\omega t]d\omega t ------3.2$$

Where

A_n and B_n are the fourier coefficients
Id is the dc load current
α is the thyristor firing angle
ωta is the value of ωt at α = 0

2π/Npm is the angular space of the pulse and ac current lasts for 2π/Npm

$$\therefore P_{fac} = \frac{Cos\ \omega ta\ Cos\ \alpha\ \sqrt{2Npm}}{\pi} \quad --- \quad --- \quad 3.3$$

$$\omega ta = \frac{\pi}{2} - \frac{\pi}{N_{nm}}$$

Where,

N_{mn} is the number of pulses
N_{pm} is the number of phases

RESULTS

The values of ωta, commonly for 2, 3 and 6 pulse numbers of the mid-point converters, were calculated and plugged into the general equation (3.3) of the power factor, and the results are as shown in table 1. Example, for a three-phase 3-pulse mid-point converter:

$$\omega ta = \frac{\pi}{2} - \frac{\pi}{N_{nm}}$$

$$= \frac{\pi}{2} - \frac{\pi}{3} = \frac{\pi}{6}\ or\ 30^o$$

$$P_{fac} = \frac{Cos\ \omega ta\ Cos\ \alpha\ \sqrt{2N_{pm}}}{\pi}$$

$$= \frac{Cos\ 30^o\ Cos\ \alpha\ \sqrt{2x3}}{\pi}$$

$$= \left(\frac{3\sqrt{2}}{2\pi}\right) Cos\ \alpha$$

Table-1: Pulse numbers and their corresponding power factors for the mid-point converters

N_{mn}	$\omega t\alpha$	P_{fac}
2	0	$\frac{2\cos\alpha}{\pi}$
3	$\frac{\pi}{6}$	$\left(\frac{3\sqrt{2}}{2\pi}\right) Cos\ \alpha$
6	$\frac{\pi}{3}$	$\left(\frac{\sqrt{3}}{\pi}\right) Cos\ \alpha$

PROPERTIES OF THE MID-POINT CONVERTERS

Features [4]:

- The mid-point converter is a phase controlled ac to dc converter where the conducting and switching method is on one-to-one basis.
- Unlike the full-bridge converters where the switching goes in pairs, it is single in mid-point converters.
- There are as many phases as there are number of thyristors in the mid-point converters.

Advantages

It has an average over the full-bridge two-pulse converters because of its use in low-power application e.g. control of low voltage motors.

Disadvantages

The main disadvantage of the mid-point converter is the bulky nature of the transformer involved because only one half of the secondary winding carries current at any instant.

Limitations

Like other phase-controlled converters, the mid-point converter gives a very poor output power and is limited to locations where the non-linear load concentration is low [5].

Applications

It is used in low-power applications, especially in control of low voltage motors [6].

ANALYSIS RESULTS

From the general equation (3.3) of the power factor obtained, other power factors for any number of pulses, commonly 2 and 3-pulse mid-point converters can be generated. First of all, the value of ωta is found and substituted in the general equation to obtain the new power factor shown in Table-1. And as the pulse number increases, the mid-point converter power factor increases and later, decreased.

CONCLUSIONS

With the various features and properties of the mid-point converters x-rayed and/or exposed, practicing engineers will find the use very important for various practical applications and uses. Hence, the mid-point converter is highly recommended.

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