

PWM Control of AC Chopper Fed by Unbalanced 3-Phase Voltage Source

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Abstract

In recent years, power electronic has become even more popular with the development of semiconductor switching devices. Power electronics applications can be found almost in all systems related to electrical and electronic fields. With the power electronic circuits, AC or DC voltages at various amplitudes can be obtained from constant voltage sources. AC voltage with constant frequency and variable amplitude with high power factor can be provided by an AC chopper. Purpose of these power electronic circuits is to make the system more efficient, provide output waveforms with higher quality (less harmonics) and prevent power loss in large power systems. In this study, a three-phase PWM controlled AC chopper circuit has been modelled and simulated in MATLAB / Simulink package program. In this simulation, the output statements obtained for the switching devices by a different control method are discussed. Various operating conditions have been examined where a three-phase unbalanced voltage source without and with having the 5th and 7th harmonics was applied to the input side of the chopper. As a result, superiority of the control system used in the PWM controlled AC chopper has been demonstrated by the simulation results.

Keywords: Three-Phase PWM AC Chopper, Hysteresis Band Current Controller (HBCC), Harmonic Analysis, Pulse width Modulation (PWM).

Dengesiz 3-Fazlı Gerilim Kaynağı ile Beslenen AA Kıyıcısının PWM Kontrolü

Özet

Son yıllarda, güç elektroniği, yarıiletken anahtarlama araçlarının da gelişimiyle birlikte daha popüler hale gelmiştir. Neredeyse elektrik ve elektronik ile ilgili tüm sistemlerde güç elektroniği uygulamaları bulunmaktadır. Güç elektroniği devreleri ile farklı genliklerdeki AA veya DA gerilimleri sabit gerilim kaynaklarından elde edilebilir. Bir AC kıyıcı ile sabit frekanslı, yüksek güç faktörlü ve değişken genlikli AA gerilimi elde edilebilir. Bu güç elektroniği devrelerinin amacı, sistemi daha verimli hale getirmek, daha yüksek kalitede (daha az harmonik) çıkış dalga formları sağlamak ve büyük güç sistemlerinde güç kaybını önlemektir. Bu çalışmada, üç fazlı PWM kontrollü AA kıyıcı devresi, MATLAB / Simulink paket programı ile modellenmiştir ve benzetimi yapılmıştır. Bu simülasyonda, farklı bir kontrol metodu ile anahtarlanan yarıiletken anahtarlar için elde edilen sonuçlar tartışılmıştır. 5. ve 7. harmoniklerin olduğu ve olmadığı üç fazlı dengesiz gerilim kaynağının kıyıcının giriş tarafına uygulandığı çeşitli çalışma koşulları incelenmiştir. Sonuç olarak, PWM kontrollü AA kıyıcıda kullanılan kontrol sisteminin üstünlüğü simülasyon sonuçları ile gösterilmiştir.

Anahtar Kelimeler: 3-Fazlı PWM AA Kıyıcı, Histerezis Bant Akım Kontrolörü (HBCC), Harmonik Analizi, Darbe Genişlik Modülasyonu (PWM).

1. Introduction

Along with the developing technology, the amount of energy consumed all over the world has also increased. Due to the amount of energy consumed, new ways have been sought to meet this energy demand. More efficient systems with smaller structures and circuits designed to consume less power loss despite adverse

conditions are required. The most popular circuit is the power electronics circuits, which are still being developed. Power electronic circuits reduce energy loss on the earth with renewable energy processing and create efficient systems for it. Power electronic circuits transform electrical power by using the switching characteristics of semiconductor elements.

AC chopper circuits of the power electronic family are the basic concept of this study. AC choppers are, at its most basic definition, a power circuit which can convert a constant frequency AC voltage to another voltage at a desired amplitude [1,2]. Single-phase and three-phase versions of the AC chopper are available. AC choppers with natural commutation have negative features such as high harmonics on the mains or load sides. AC choppers are used in many industrial areas. Frequent use of such power electronic circuits has led to poor quality in energy systems [2]. It is possible to further improve AC choppers by eliminating these undesirable features. With the use of power electronic devices which can operate at high switching frequencies, the PWM method has begun to be used in the chopper circuits [3]. PWM AC chopping circuits have reduced side effects of the natural commutated ones as well as have become a special application of these circuits [3,4].

In this study, it is aimed to obtain load current with less harmonics by applying Hysteresis Band Current Controller (HBCC) technique for three-phase PWM AC chopper. The HBCC technique is preferred because of its dynamic response and simplicity [5]. Thanks to this controller, whatever the input voltage of the system is, a load current with very low harmonics at the output is obtained. The results will be quite advantageous for all power electronics-based systems.

2. Hysteresis Band Current Controller for a Three Phase AC Chopper

Fig.1 shows the circuit schema of the three-phase AC chopper [6]. The simulation model of this circuit using MATLAB / Simulink is shown in Fig. 2 [6]. IGBTs are used as switching semiconductor devices and a three-phase $R-L$ load is used at the output. Depending on the nature of the load used, there will be a load phase angle between the voltage and current space vectors of the source. The reference currents in the AC chopper must have the same frequency as the source voltage and the same phase angle as that of the load [6]. With the

HBCC technique, the reference currents are obtained and the continuity of the load current paths is ensured [6].

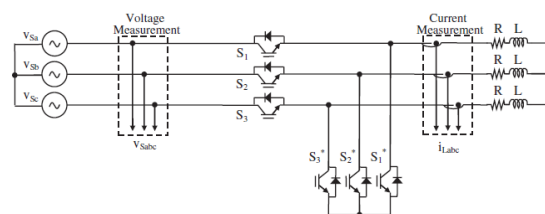


Fig. 1. The power scheme of the three-phase PWM AC chopper [6]

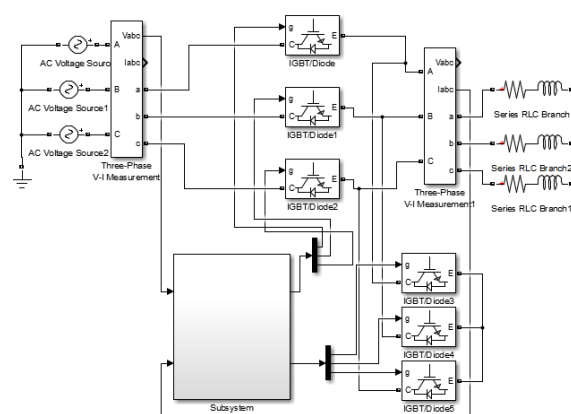


Fig. 2. The Simulink model of the three-phase PWM AC chopper

The reference currents can be obtained using phase locked loop (PLL) or using abc/dq transformations called Park Transform. The continuity of the load current conduction paths is also provided using the technique called the minimum voltage algorithm [3,6]. The minimum voltage algorithm ensures the continuity of the resulting current paths by triggering the correct switch according to the instantaneous values of the source voltage [3,6].

In the proposed model, the on and off states of the switches are provided using specific switching states. The goal is to obtain high quality waveforms at the output whatever the input voltage source is. In order to demonstrate the superiority of the control system, three-phase voltage source having harmonics or unbalanced input. Undesirable changes in the source voltage (such as noise or harmonic distortion) will directly affect the output voltage and hence the

amplitude of the output current. To analyze this situation, the fifth and seventh harmonics of the input voltage source are added to the input with certain amplitude ratios [7].

2.1. Analysis of HBCC technique applied to AC chopper

Any kind of load can be controlled with the PWM AC chopper connected to the three-phase source. The PLL block shown in Fig. 3 is used to set the source frequency [6]. The *abc / dq* transform block is also used to set the load phase. Only the amplitudes of the generated reference currents are input to the control system depending on the demand.

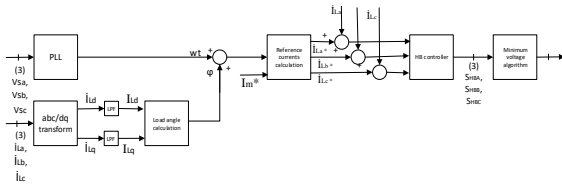


Fig. 3. The application of the HBCC theory [6]

The minimum voltage algorithm can be used in various systems. For instance, in a 3-phase inverter as the 3-phase chopping operation is made independent of each other, the current flow is continuous. In the proposed topology, the chopping procedures depend on each other and the flow paths are separated from each other during the phase chopping operation. The minimum voltage algorithm is used to prevent such undesirable situations. Depending on the instance, the switch with the minimum voltage is kept off while the chopper continues to operate in the other two phases and the sum of these currents returns from the phase with the minimum voltage.

2.2. Switching states

Besides the values in Table 1, four different switching states have been performed.

Table 1. System parameters used in simulation

Parameters	Values
Source	$V_{sA} = 220 \text{ V}$ (rms)
	$f = 50 \text{ Hz}$
Load	$L = 20 \text{ mH}$
	$R = 10 \Omega$

By referring to Fig.1, the following switching situations exist:

Table 2. Switching situations

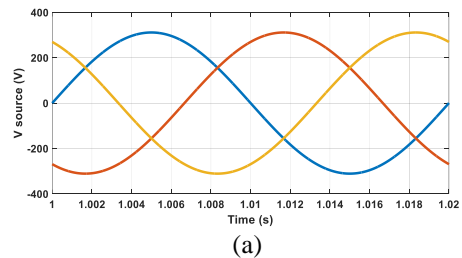
Switching States	ON	OFF
1	S_1, S_1^*, S_2^* and S_3^*	S_2 and S_3
2	S_1, S_3, S_1^* and S_2^*	S_2 and S_3^*
3	S_1, S_2, S_1^* and S_3^*	S_3 and S_2^*
4	S_1, S_2, S_3 and S_1^*	-

3. Analyses

In the simulation, two different conditions were performed. The first condition is used to observe the effect of the distorted three-phase input supply on a three-phase *R-L* load where no power electronic circuit was used and the load is directly connected to the input supply as shown in Fig. 4. The second condition is to observe the effect of the same source voltage on *R-L* load using HBCC technique applied to PWM AC chopper.

3.1. Analysis of the proposed system fed by 3-phase input supply

In this application, a balanced and undistorted three phase voltage set is applied to the system input. In this case, the wave form of the load current of the system is observed to be smooth. The waveforms obtained are as follows for a complete period:



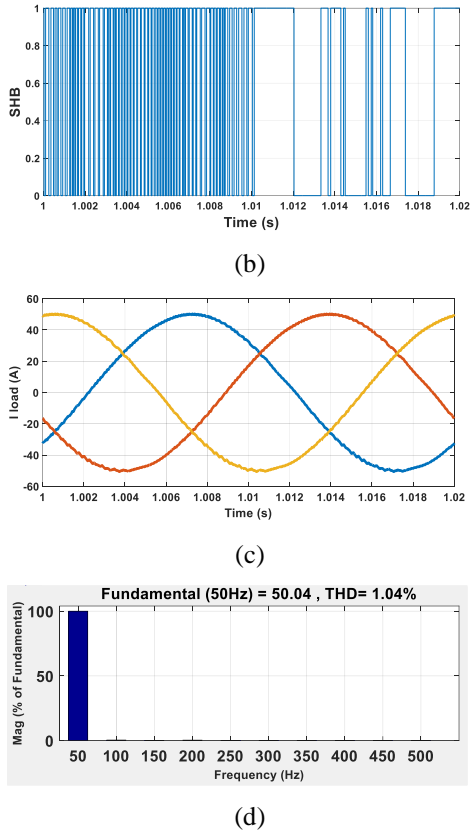


Fig.4. Simulation results of the PWM AC chopper fed by a distorted 3-phase supply and feeding a three-phase star connected R-L load. (a) Voltage source, (b) Switching signal, (c) Load current, (d) The harmonic spectrum of the load current.

In the Fig.4, 1-1.02 s is selected as a full period interval to see more clearly the waveform and harmonic analysis of the load current. Since the circuit is still in transient state at 0-0.02 s, the waveforms are harmonic. Therefore, the period of 1-1.02 s reached the permanent status has been taken into account. In this range, reference current is $I=50 A$. With the obtained waveforms and FFT analysis, it can be said that the harmonics are at an acceptable level.

In this application, Total Harmonic Distortion (THD) of the load voltage waveform is 1.04%. These results show us how reasonable and feasible the controller proposed for the three-phase PWM chopper.

3.2. Analysis of 3-phase star-connected r-l load fed by a distorted three-phase input supply

Undesirable changes in the source voltage such as noise or harmonic distortion will directly affect the output voltage and hence amplitude of the output current. To demonstrate these effects, the fifth and seventh harmonics of the input voltage set are added at certain amplitude ratios in the simulation model.

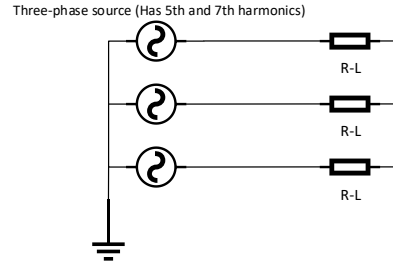


Fig. 5. A star-connected 3-phase system with harmonic voltage applied to the input

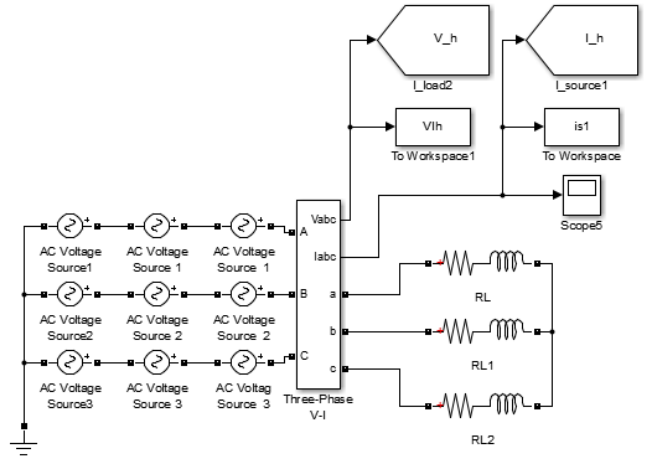


Fig. 6. Simulation Model of the star-connected 3-phase system with harmonic voltage applied to the input

In order to demonstrate the superiority of the AC chopper system used in this work, a distorted supply voltage model is created in Simulink/Matlab to be used as input to the system. The three-phase sinusoidal voltage source with harmonics is defined as follows:

$$V_{1h} = k_1 \cos(5\omega t) + k_2 \cos(7\omega t) \quad (1)$$

$$V_{2h} = k_1 \cos\left(5\omega t - \frac{2\pi}{3}\right) + k_2 \cos\left(7\omega t + \frac{2\pi}{3}\right) \quad (2)$$

$$V_{3h} = k_1 \cos\left(5\omega t + \frac{2\pi}{3}\right) + k_2 \cos\left(7\omega t - \frac{2\pi}{3}\right) \quad (3)$$

The k_1 and k_2 values in Eq.(1-3) are set to be about 10% of the supply voltages [7]. V_{1h} , V_{2h} and V_{3h} are the harmonic voltages of A, B and C phases, respectively. The resulting simulation waveforms are given in Fig. 6 for a full period.

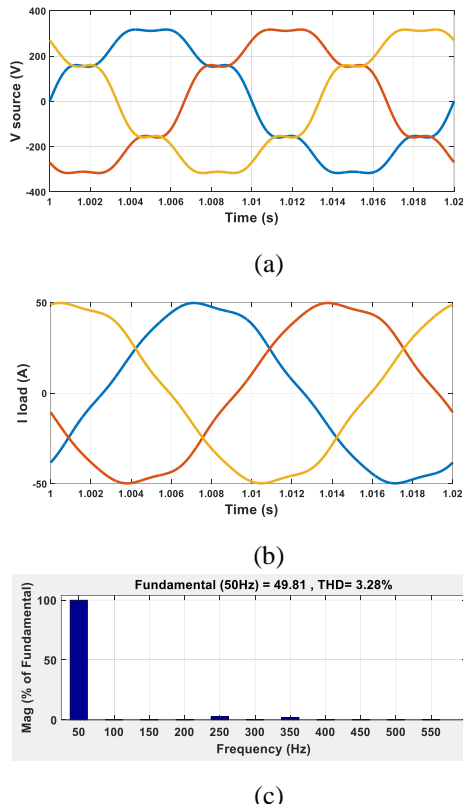


Fig.7. Simulation results of star-connected 3-phase load fed by a distorted 3-phase supply, (a) Distorted source voltages, (b) Load currents, (c) The harmonic spectrum of the load current.

As can be seen in Fig.7, when a voltage source with harmonics is applied directly to the $R-L$ load, all harmonics of the supply are reflected to the output. THD of the load current waveform is 3.28%.

3.3. Analysis of the proposed system fed by a distorted 3-phase input supply

In this case, three-phase voltage supply with 5th and 7th harmonics used in the previous system was also applied to the input of the PWM AC chopper controlled by the HBCC. The Simulink model of the system including the distorted voltage supply source is illustrated in

Fig.8. Comparing to the previous system, the superiority of the proposed method in [6] is confirmed by the simulation results in Fig.9. It is observed that the system gives successful results, that is, the waveforms of the load currents and voltages have sufficient quality. The simulation results taken for a complete period are shown in Fig. 9.

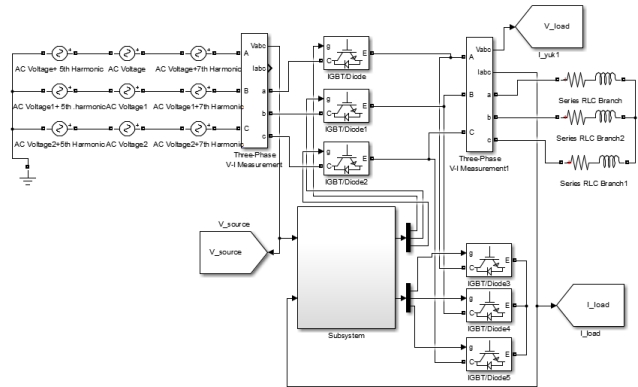


Fig. 8. Simulink model for 3-phase PWM AC chopper fed by a distorted input supply

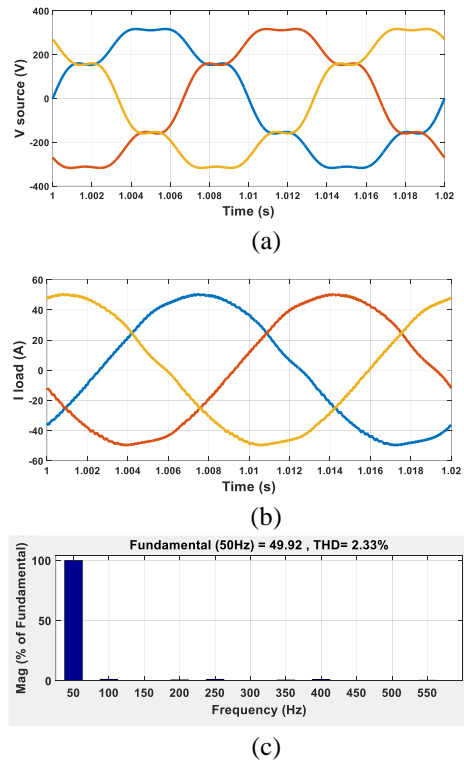


Fig.9. Simulation results of the PWM AC chopper fed by a distorted 3-phase supply and feeding a three-phase star connected $R-L$ load. (a) Voltage source, (b) Load current, (c) The harmonic spectrum of the load current.

As can be seen in the Fig.9 (b), the resulting load current waveforms have less harmonics than expected and their shapes are almost pure sinusoidal waveforms. As seen in Fig.9 (c), main harmonics are much dominant. This is why the hysteresis band controller is used in the simulation and proposed in [6]. Thanks to this controller the switches used in the chopper are controlled in a manner to have less harmonics at the output. The controller in simulation are designed for analysing the parameter of voltage and current. In general, it has features such as reducing the harmonic components and increasing the power factor of a particular circuit.

In this study, Total Harmonic Distortion (THD) of the load voltage waveform is 2.33%. These results show us how reasonable and feasible the controller proposed for the three-phase PWM chopper.

4. Conclusions

In this study, a PWM AC chopper with hysteresis band controller has been modelled and simulated with the Simulink/MATLAB package program. It is aimed to have more efficient chopper comparing to the traditional 3-phase AC chopper. Although, the traditional phase controlled AC chopper has not been simulated in this work, its waveforms are well known. Therefore, it could be easily stated that the performance of the proposed system would be much better than that of the traditional AC chopper. In addition, operating conditions of the PWM AC chopper have been made much worst by adding the 5th and 7th harmonics to the input voltage waveforms. Even so promising simulation results have been obtained. The simulation results show that the proposed control

algorithm minimizes the amount of THD at the output currents. Despite of the voltages with harmonics applied to the input, three-phase currents at the output are stable and they consist of very low amount of harmonics because of the HBCC used. As a result, the ratio of harmonics is reduced significantly with the switching control algorithm. These results have been supported by the harmonic analysis.

5. References

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