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Study of High Frequency Electromagnetic Disturbances Generated by a Rectifier and Chopper Association

Abstract. *This paper discusses the electromagnetic disturbances generated by a rectifier and a chopper association which is frequently encountered in power electronics. The paper presents the basic principles of electromagnetic interferences in power electronics and an EMC study of the considered device that is namely the rectifier and chopper association. The problems involved in temporal or frequential simulations are highlighted in this study. A comparison between our simulation results and experimental one's taken from literature is also presented in this paper. At the close of this study we recommended the use of EMC filtering to reduce the rectifier and chopper association disturbances at acceptable levels which are specified by EMC standards. The main conclusion of the paper is that this device is really electromagnetic pollutant and must then be taken into account, as a whole, in any study implying this kind of converters.*

Streszczenie. *W artykule analizuję się zakłócenia elektromagnetyczne generowane przez układ prostownika i choppera. Wyniki symulacji porównano z wynikami eksperymentalnymi. Zaproponowano układ filtrowania zakłóceń. (**Analiza zakłóceń elektromagnetycznych generowanych przez układ prostownika z chopperem**)*

Keywords: Electromagnetic compatibility (EMC), power electronics, rectifier-chopper association, conducted disturbances, filtering.
Słowa kluczowe: kompatybilnośc elektromagnetyczna, zakłócenia elektromagnetyczne, prostownik.

Introduction

Today, Electromagnetic Compatibility (EMC) seems to be one of the major constraints of power electronics converters. Unfortunately, it is too often regarded as the last phase of the development of a converter since it represents the last step of its marketing. The estimation of conducted and radiated disturbances by simulation offers a considerable gain from the economic point of view [1], [2].

Indeed, static power converters, such as rectifiers and choppers, operate at increasingly high frequencies. They generate stiff voltages and currents (disruptive signals) which causes conducted and radiated electromagnetic interferences. These signals propagate towards the power supply source of the static converter itself and towards the load which is feeding [3], [4].

Moreover, the origin of the electromagnetic disturbances generated by a static conversion can be apprehended by an electric modeling of type «circuit». This one can, also, be used to simulate the EMC behavior of the structure, rather easily as regards the conducted currents thanks to solvers of type « circuit » such as MATLAB, PSpice, SABER, PSIM, PACT or others.

In power networks, the actual current or voltage wave's shapes are usually quite different from a pure sinusoid which characterizes the alternating current delivered by the electrical power station. This was due to the fact that the electrical equipments, such as static converters, connected on these networks, are frequently of non linear characteristics generating thus electromagnetic disturbances which propagate towards the power network and mingle with the useful signals causing malfunctions in a number of devices or neighbors systems.

The present work is dedicated to the study of high frequencies conducted electromagnetic disturbances engendered by a rectifier and chopper association. So to highlight these disturbances we have performed simulations consisting in the examination of the disruptive effects due to the switching cells of power switches (Diodes and MOSFET) being part of the studied converter's structure.

Electromagnetic interferences in power electronics

In the context of power electronics, the EMC aspects will take mainly two particularities [5], [6]:

1. Static converters are both "sources" and "victims" of disturbances.
2. Converters generate EM disturbances in a large frequency spectrum (low and high-frequencies).

To establish equations relating to disturbances in the differential mode (*DM*) and in the common mode (*CM*) relative to a static converter, a simple case of conducted disturbances generator is presented in Figure (1). In this figure, V_N represents the disturbance voltage generated in the converter. Z_1 and Z_2 are the impedances denoting the noise propagation paths; Z_{C1} is the impedance between the converter and the ground. Resistors R_{C1} and R_{C2} are the noising load. They are normalized resistors (50Ω) at which the parasitic voltages, generated by the considered device, are measured.

The disruptive currents circulating in power lines and ground gives are the following expressions [7], [8]:

$$i_1 = -i_{CM} + i_{DM} \quad (1)$$

$$i_2 = -i_{CM} - i_{DM} \quad (2)$$

$$i_G = 2\, i_{CM} \quad (3)$$

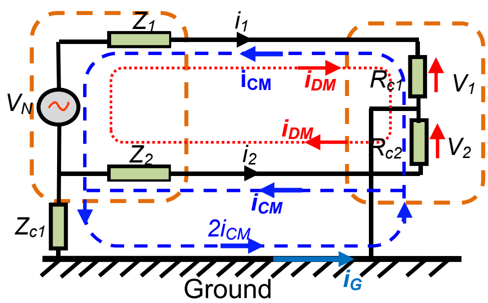


Fig.1. DM and CM noise [7]

The EMI standards specify the voltage limits of noise on the normalized resistance R_c (such as $R_c = R_{c1} = Rc_2 = 50\Omega$), which are:

$$V_1 = R_C\,(-i_{CM} + i_{DM}) \quad (4)$$

$$V_2 = R_C\,(-i_{CM} - i_{DM}) \quad (5)$$

Disturbances in common mode (*CM*) and in differential mode (*DM*) are represented by:

(6) $V_{CM} = -R_C\, i_{CM} = (V_1 + V_2)/2$

(7) $V_{DM} = R_C\, i_{DM} = (V_1 - V_2)/2$

Voltages V_1, V_2, V_{CM} and V_{DM} are linked by:

(8) $V_1 = V_{CM} + V_{DM}$

(9) $V_2 = V_{CM} - V_{DM}$

EMC study of a rectifier and a chopper association

In this part of study we present an evaluation of the EMC effects on a power network introduced by the association of two polluting devices that is to say a rectifier and a chopper. Thus, in the assembly scheme, the diodes bridge is inserted between the Line Impedance Stabilization Network (LISN) and the chopper (Fig.2).

Otherwise, if the internal impedance of the bridge diodes (rectifier), in the conducting step, is considered negligible compared to all others, the rectifier behaves as a disturbances leader according to the state of diodes.

Therefore, the disturbances generated by the interaction between the diodes bridge and the LISN are superimposed on those issued from the chopper. This also supposes that the chopper noise does not modify the diodes time conduction because in the opposite case disturbances are not uncorrelated and their superimposing is not valid. So, to simplify this study and in order to present only phenomenological aspects, we suppose that the disturbances characteristic to the chopper do not modify the bridge functioning point. We can then separate the two disturbances modes relative to the chopper, and then treat separately the differential mode and the common mode.

We obtain in this way three temporal functions: $F_{bridge}(t)$, $F_{DM}(t)$ and $F_{CM}(t)$ such as:

$F_{bridge}(t)$: representing the rectifier disturbances on a half-period of the power network period.

$F_{DM}(t)$: the chopper disturbances in the differential mode on one chopping period.

$F_{CM}(t)$: the chopper disturbances in the common mode on one chopping period.

We also suppose that the cutting frequency is a multiple of the power network frequency.

The temporal function representing, over a period, all disturbances is given by the following equations:

(10) $F_{tot}(t) = F_{bridge}(t) + F_{chopper}(t)$

(11) $F_{chopper}(t) = f(F_{DM}(t), (F_{CM}(t))$

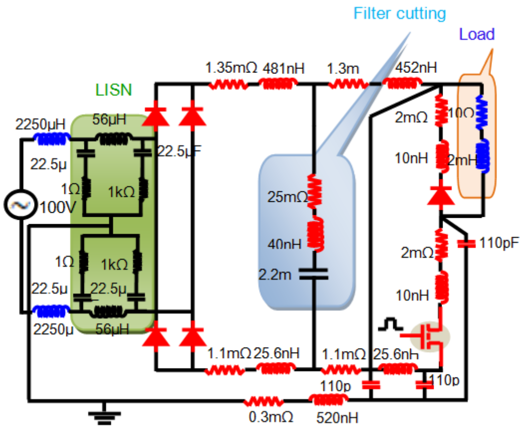


Fig.2.Rectifier-Chopper association - Assembly scheme

To illustrate the EM disturbances impact generated by the chopper in the conducting step of diodes, the diodes bridge is directly loaded by a step-down chopper. In this context we have simulated, under PSpice, the circuit shown in Figure 2. In this simulation, we have taken into account the inductive and capacitive parasitic elements. The used diodes are of type BYT600P12 and the used MOSFET is of type IRFP750.

Simulation Results

In Figure 3 we present the temporal voltage variations at the bridge rectifier input and the temporal variations of the line current. In Figure 4, are drawn the temporal voltage variations at the rectifier bridge output and the temporal variations of the line current. On figure 5, we postponed the shape of conducted disturbances channeled towards the LISN equivalent measure resistance. According to figures 3 and 4, it is obvious that the current waveform has a similar shape to the one obtained in the rectifier loaded by a simple resistor case.

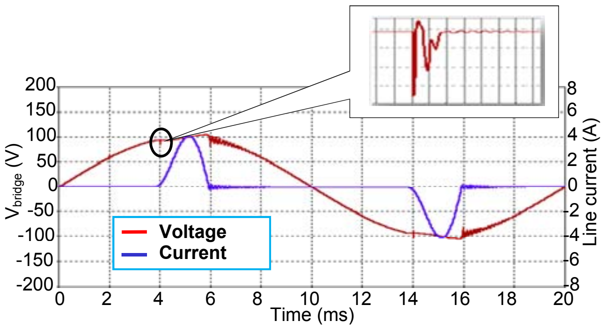


Fig.3. Temporal variations of the bridge rectifier input voltage and of the line current

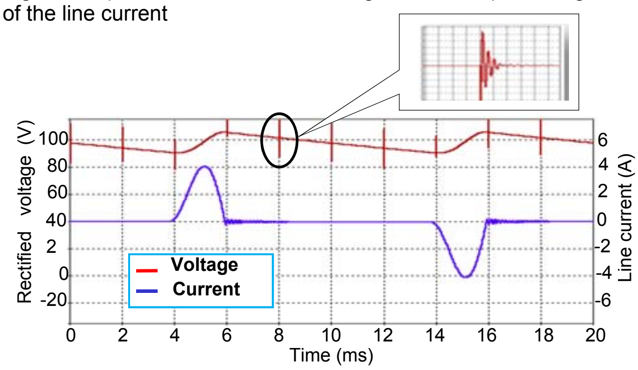


Fig. 4. Temporal variations of the bridge rectifier output voltage and of the line current

However the rectified voltage and the input rectifier bridge voltage waveforms are distorted by abrupt changes due to MOSFET and diodes switching. When we make a zoom corresponding to the switching time interval, a periodic and oscillatory phenomenon is visible. This phenomenon is due to the brutal switching of switches and to the effects of connecting inductors and to the passive components of converters.

Furthermore, another oscillatory phenomenon appears on the input voltage waveform of the bridge. It is due to the rectifier diodes blocking. The result presented into the figure (5) allows us to assess the spectral level of disturbances due to the rectifier-chopper association. In this figure we can clearly notice the fast voltage variation across the LISN equivalent resistance. It appears on the zoomed part of figure (5) the oscillatory shape of the disturbances during the MOSFET switching. Another zone indicated, in this figure, by the black circle, represents the disturbances generated during the MOSFET switching phase and the blocking phase of one rectifying diode.

To illustrate the spectral level of these disturbances and to compare it with the standards specifications sizes relative to the concerned conducted disturbances, the use of the frequency representation is indispensable. So, we present respectively in figures 6 and 7 the spectral analysis of the total disturbances and of the differential and common mode disturbances. Otherwise, by worry of well explain these spectra; we have separated them in two zones. These zones have been chosen according to both pollution sources considered in this application. In this way, the zone "1" shows the disturbances due to the rectifier diodes switching while zone "2" highlight the MOSFET switching disturbances. We notice that the levels of the EM disturbances spectra exceed the limits imposed by standard EMC FCC Class B.

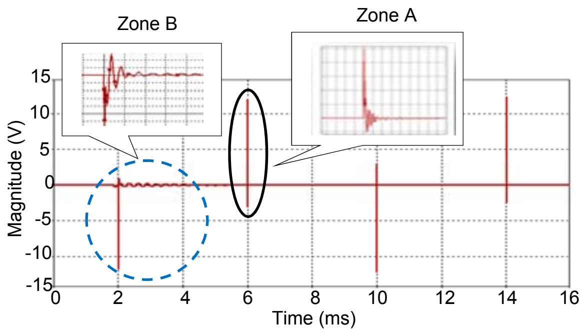


Fig. 5. LISN equivalent resistance terminal voltag

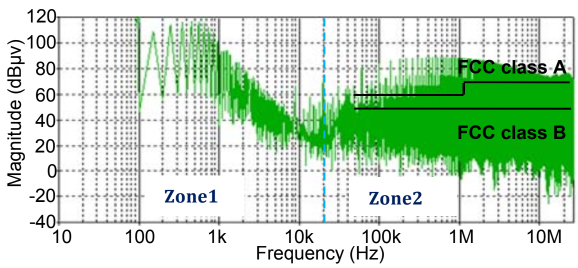


Fig. 6. Total disturbances spectrum due to the rectifier-chopper association

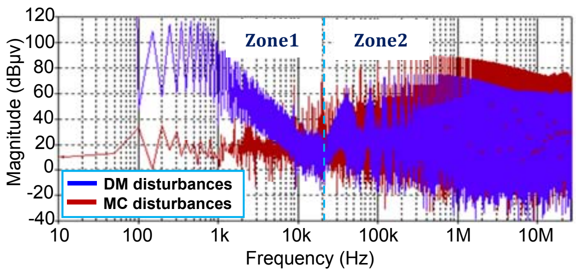
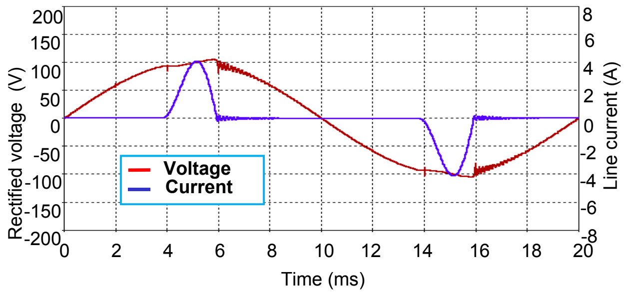


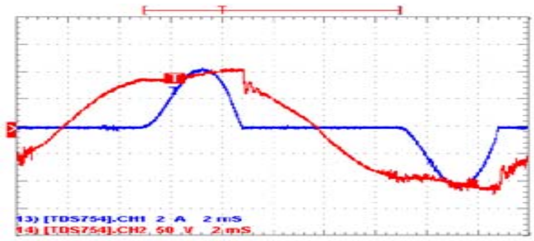
Fig. 7 . Differential and common mode disturbances

Results validation

In order to validate our simulation results we have In order to validate our simulation results we have exploited the experimental results presented in the reference [9]. To this end, we have presented respectively on figures (8) and (9) the voltage and current waveforms at the input and output of the bridge rectifier obtained by simulation and by measurement [9]. The power network voltage waveform is presented in the figure (10). The comparison between simulation and measured results has shown a good agreement. However, some differences which appear between the measured and simulated waveforms could be explained by the several power network imperfections which have not been taken into account in this study. Among these imperfections, we can distinguish the power network voltage which is often distorted as depicted in figure 10.

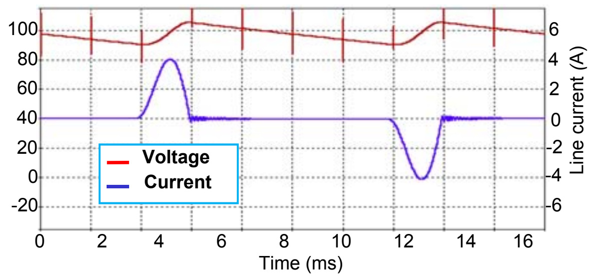


a) Our simulation results

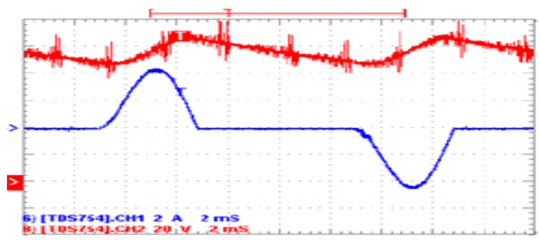


b) Experimental results taken from reference [9]

Fig. 8. Temporal variations of the bridge rectifier input voltage and of the line current

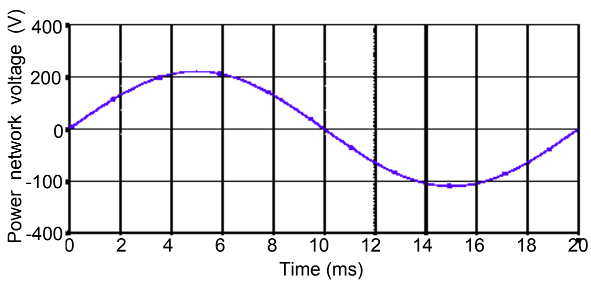


a) Our simulation results

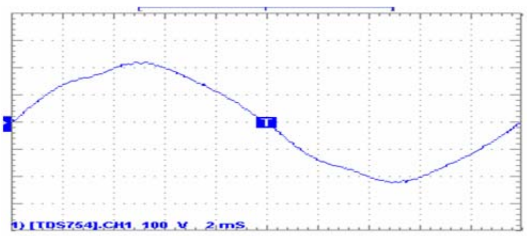


b) Experimental results taken from reference [9]

Fig. 9. Temporal variations of the bridge rectifier output voltage and of the line current



a) Our simulation results



b) Experimental results taken from reference [9]

Fig. 10. Power Network no load voltage

EMC filters

To resolve EMC problems, it is necessary to be able to act on disturbances sources, on the coupling mechanism or still on disturbances receivers in order to desensitize them. Also, in this paper, we propose the use of a filtering technical to reduce the EM disturbances generated by power electronics devices especially static converters. Initially, it is important to remind that filtering is an operation consisting in separating of signal components according to their frequencies. In power electronics, EMC filters are a necessary interface between the power network and static converters.

A practical approach was proposed by the authors of references [10], [11], [12], [13] and [14] to facilitate the design of such filters. The proposed design procedure, adapted only in high frequency range, can be summarized as follows:

First Step

Simulation of:
- The total EM disturbances
- The common and differential EM disturbances modes.

Second Step

Determining of:
- The $(V_{req\text{-}CM})_{dB}$ attenuation due to the common EM disturbances mode.
- The $(V_{req\text{-}DM})_{dB}$ attenuation due to the differential EM disturbances mode.

The mathematical expressions of these attenuations are:

(12) $$(V_{req-CM})_{dB} = (V_{CM_{max}})_{dB} - (V_{lim})_{dB} + 6dB$$

(13) $$(V_{req-DM})_{dB} = (V_{DM_{max}})_{dB} - (V_{lim})_{dB} + 6dB$$

With:

$(V_{DM})_{dB}$ and $(V_{CM})_{dB}$: representing the EM disturbances voltages of the line corresponding to the first step of the designing procedure.

$(V_{lim})_{dB}$: is the limit of the conducted emissions specified by the EMC standards.

To avoid conception errors, a bias of *"+6 dB"* is necessary [15].

Third Step

Evaluation of the *LC* filter cut-off frequencies by looking for the minima values of $f_{c\text{-}CM}$ and $f_{c\text{-}DM}$ with the use of the following equations:

(14) $$(V_{req-CM})_{dB} = 40\log_{10}(f_{CM_{max}}/f_{c-CM})$$

(15) $$(V_{req-DM})_{dB} = 40\log_{10}(f_{DM_{max}}/f_{c-DM})$$

where: $f_{c\text{-}CM}$ and $f_{c\text{-}DM}$ indicates respectively the cut-off frequencies of both designed filters for conducted disturbances in common *(CM)* and differential mode *(MD)*.

$f_{CM\ max}$ and $f_{DM\ max}$ are respectively the frequencies where the conducted disturbances spectrum, in common and in differential mode, has a maximal amplitude.

Fourth Step

Calculating respectively the inductors and capacitors filters values: (L_{CM}, C_{CM}) and (L_{DM}, C_{DM}) using the following equations:

(16) $$f_{c-CM} = 1/\left(2\pi\sqrt{L_{CM}C_{CM}}\right)$$

(17) $$f_{c-DM} = 1/\left(2\pi\sqrt{L_{DM}C_{DM}}\right)$$

Figure (11) shows a typical topology of an EMC filter. This topology possesses equivalent circuits in the common and in the differential mode. The inductor L_{CM} and the capacitor $C_y = C_{CM}/2$ are used to suppress the common mode noise while the inductor L_{DM} and the capacitor $C_x = C_{DM}$ are used to suppress the differential mode noise.

Capacitors associated to the differential mode C_x allow the short-circuiting of the current relative to this mode. The capacitors of the common mode C_y, connected with the ground, short-circuit the current of the common mode. In practice, the common mode inductance is realized by two inductances wounded on a magnetic core. This inductance presents great impedance only for the common mode allowing for the filter to minimize the EM interferences reaching to the power network.

This filter topology gives typically for the common mode an attenuation of *40 dB/decade,* and the same value for the differential mode. The frequency range of attenuation is limited in low frequencies by the cut-off frequencies given by equations (16) and (17) for the two propagation modes.

Equations (16) and (17) can also be written as:

(18) $$f_{c-CM} = 1/\left(2\pi\sqrt{L_{CM}C_y}\right)$$

(19) $$f_{c-DM} = 1/\left(2\pi\sqrt{L_{DM}C_x}\right)$$

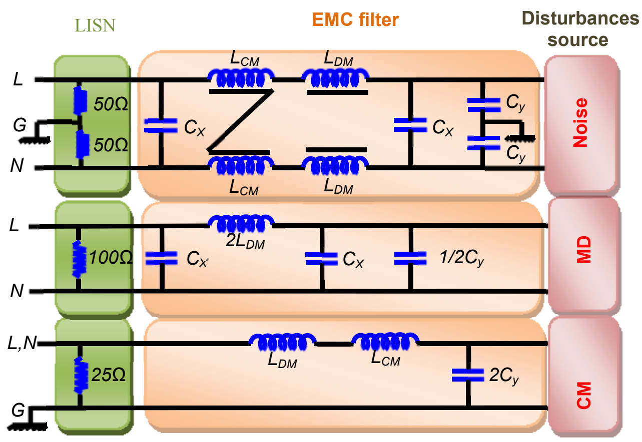


Fig. 11.Typical topology of an EMC filter used in the CM and DM modes [7], [12], [13], [16]

Results and analysis

The total disturbances spectra obtained in the case of using the EMC filter and in the case of no using filter are presented in figure (12). In the latter it is mentioned the standards specifications template relative to conducted disturbances (FCC Class A and Class B). According to the results presented in figure (12), we find that the spectrum of conducted disturbances after filtering undergoes a sufficient decrease respecting thus the FCC-Class B limits. We can also notice that this spectrum has frequencies more reduced in amplitude and widely below the limits in “zone 2”. However, in “zone 1“, there is not any changes in the frequencies amplitudes as expected because the presented filter is adapted only for high frequencies. These obtained results show the efficiency of the used filter and allows us to adopt the filtering technical as a good solution for reducing disturbances in the interval frequency ranging from 450KHz to 30MHz; interval which is required by the FCC standards.

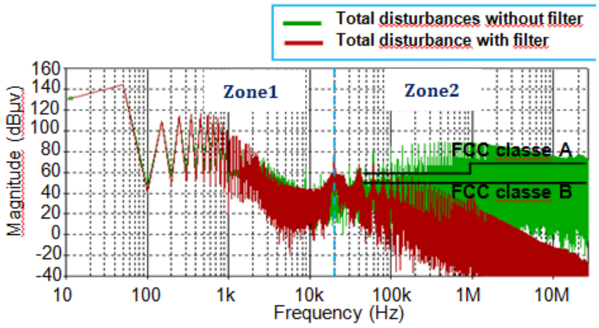


Fig. 12. Total disturbances with and without filter spectrum corresponding to the association rectifier-chopper

Conclusion

The paper presented a study of electromagnetic disturbances generated by a rectifier-chopper association which is used today in a lot of industrial applications. In a first phase we have given rise to the electromagnetic pollution effects introduced by this power electronic device. Then we have successfully implemented the superimposing technical of chopper disturbances and those due to the rectifier. We have also shown that the obtained spectrum in the high frequency range corresponds to the disturbance due to the chopper only. This phenomenon can be explained by the existence of a switching cell generating of crenellations of strong *dI/ dt* and *dV/dt*.

However, in low frequency range, the obtained spectrum corresponds to the rectifier diodes switching disturbances. It was then possible to conclude that the rectifier disturbances do not interfere with those induced by the chopper, and that each converter has a different disruptive spectrum. Finally, we studied the feasibility of a filtering technical in the protection philosophy of the considered device.

The main conclusion is that the EMC filtering is a good approach to reduce the conducted disturbances, generated by the rectifier and chopper association, below the limits required by the EMC specifications.

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