

## PFC Strategies in light of EN 61000-3-2

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**Abstract-** This paper discusses the causes of input current distortion in ac-dc single-phase rectifier-capacitor filter circuits. The paper also explains the mandatory low-frequency harmonic limits of the European standard EN-61000-3-2 and the way in which these are applied to these circuits. Different power-factor correction (PFC) techniques and strategies useful for meeting this standard are explored in this paper. Simulations and measurement results are provided for some of the techniques.

After providing an understanding of the Class A/D limits of the standard, the transition boundary between them is defined. The practical differences between the Class A/D limits and why it is easier to meet the Class A limits, is clearly explained. Three practical and popular power factor correction strategies are discussed. The passive PFC approach with its various advantages and disadvantages is explained. A solution to the requirement of having a variable inductance for rectifier circuits that have a variable load, towards meeting the Class A limits, is proposed. After this the low frequency active PFC is described. Lastly the popular high frequency active PFC scheme is discussed explaining its clear advantages of being able to simulate a unity power factor resistive load.

This paper will add to the discussion concerning the harmonic limits by providing a number of feasible methods for limiting the harmonic distortion and complying with EN/IEC 61000-3-2 and other (future) standards.

**Index Terms**—Active Power Factor correction, European standard EN-61000-3-2, Passive Power Factor correction, Harmonic Currents, Mains Network.

### I. INTRODUCTION

There has been a need to control disturbances to the supply network almost since it was first constructed in the late 19th century. The first of these was the British Lighting Clauses Act of 1899 that prevented uncontrolled arc-lamps from causing flicker on incandescent lamps. With the growth of electronic equipment in the 1970's, it became necessary to control the disturbances caused by these increasing electronic equipment, and the relevant Standards IEC555-2 and IEC555-3 were published in 1978. These then only applied to domestic equipment and were applied on a voluntary basis particularly by the television industry.

The growth of consumer electronics has meant that the average home has a plethora of mains driven electronic devices and not just television sets. Invariably these

electronic devices have mains rectification circuits, which is the dominant cause of mains harmonic distortion. Most modern electrical and electronic apparatus use some form of ac to dc power supply within their architecture and it is these supplies that draw pulses of current from the ac network during each half cycle of the supply waveform. The amount of reactive power drawn by a single apparatus (a domestic television for example) may be small, but within a typical street there may be 100 or more TVs drawing reactive power from the same supply phase resulting in a significant amount of reactive current flow and generation of harmonics.

The domestic tariff meters do not detect this reactive current and the mismatch between the power generated and that used results in a loss of revenue to the utilities. Furthermore 3-phase unbalance can also be created within a housing scheme since different streets are supplied on different phases. The unbalance current flows in the neutral line of a star configuration causing heating and in extreme cases cause burn out of the conductor. Also the reactive current manifests itself as distortion of the voltage waveform of the ac supply. If an apparatus is sensitive to such voltage distortion, an EMC problem exists. Moreover the harmonic content of this pulsating current causes additional losses and dielectric stresses in capacitors and cables, increasing currents in windings of rotating machinery and transformers and noise emissions in many products, and bringing about early failure of fuses and other safety components.

The major contributor to this problem in electronic apparatus is the mains rectifier. The situation is often seen in off line switch mode power supplies but it is not a consequence of the switching process but rather the mains rectification. A typical off line switch mode power supply will contain a full bridge rectifier connected directly to the live and neutral lines and feeding a large smoothing / hold-up capacitor. It is this combination that is the source of the trouble. Current is drawn from the supply when the input voltage exceeds that of the smoothing capacitor. When this occurs, the current is only limited by the source impedance of the mains, the resistance of the diode and capacitor. As a consequence, a current waveform rich in harmonics results. Analysis of the current waveform will show that it consists

of the fundamental 50 Hz component, a third harmonic at 150 Hz, a fifth at 250 Hz and so on. The number of harmonics present is determined by the rise and fall time of the current and their relative magnitudes by the particular wave shape formed.

As the ac mains exhibit non-zero source impedance, the high current peaks cause some clipping distortion on the peaks of the voltage sinusoid. Fourier analysis shows that this in turn also lowers the power factor significantly.

Fig. 1a/1b explains the situation more clearly. When more than one power supply operates from such distorted mains, the problem is compounded as each power supply charges its input capacitor from the same peak of the ac voltage.

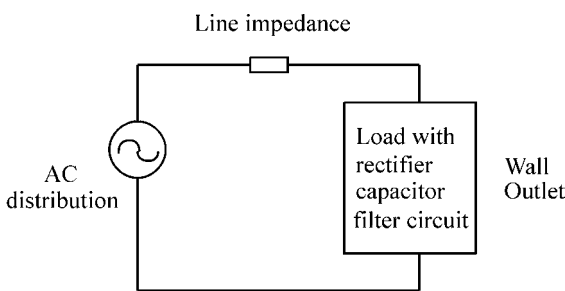


Fig. 1a. Equivalent circuit of a typical off line SMPS

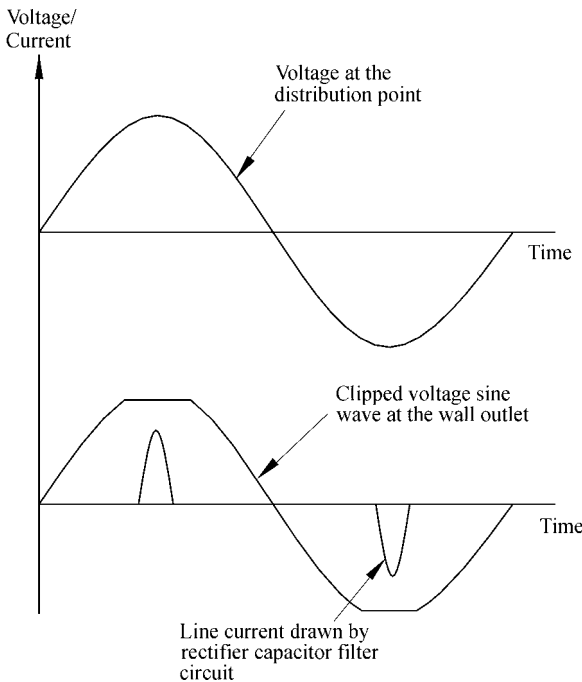


Fig. 1b. Voltage distortion caused by rectifier capacitor circuits

The effect of poor power factor and harmonics generated by rectifier-capacitor filter circuits has been a matter of concern for long. Thus Harmonics must be filtered and this

has led to the creation of the EN 61000-3-2 standard [1] and its adoption by the European Community. A closer look at the standard shows that it is concerned only about input current harmonic distortion. It enforces the reduction of harmonics generated by equipment connected to the network. It is important to notice that the standard does not require a complete suppression of input current harmonics. Further there are no requirements of improving the power factor of these equipment. Thus, without the suppression of harmonics completely, a distortion-limiting network would help meet the standard despite a non-unity power factor of the converter. Therefore with increasing number of equipment getting connected to the network, the total harmonic current circulating in the network could only be increasing everyday.

This paper discusses the causes of input current distortion in ac-dc single phase rectifier- capacitor filter circuits and understands the mandatory low-frequency harmonic limits of the European standard EN 61000-3-2 that is applicable for these rectifier-capacitor filter circuits. Different Power Factor Correction (PFC) techniques / strategies [2] useful for meeting this standard and mitigate this problem, is explored in this paper. Some simulations and measurement results are also provided.

## II. EN 61000-3-2, THE EUROPEAN STANDARD ON LOW FREQUENCY HARMONIC LIMITS.

The above discussion just shows a few problems power-generating plants and the distribution systems are confronted with. To mitigate this problem, it is now legally mandatory to limit the harmonic currents from any equipment connected to the public utility grid in the European Union. The applicable low-frequency harmonic limits are guided by the European standard EN 61000-3-2:2000 presently.

Though it is a common notion that this standard requires some kind of power factor correction at the input of these equipment connected to the public utility grid, this is actually a common misunderstanding. Instead, the standard requires that these equipment connected to the public utility grid be firstly classified to Class A/B/C or D and that their low-frequency harmonic currents be limited to values that are equal to or lower than that is applicable for that class of equipment. For offline rectifier applications, only Class A/D limits are applicable. Class B/C limits covers portable tools, lighting equipment, etc.

Thus the standard imposes an indirect limit on the load power factor. With the maximum current allowed for each harmonic being fixed (Class A/D limits), the minimum power factor is automatically restricted indirectly by the standard. Thus as power levels of a converter increases, its power factor must improve accordingly to continue meeting the easiest to meet Class A limits of the standard. In fact for power levels of 2500 W, the input power factor

should be close to unity. Other regulations, such as EN60555-2, are being considered and this may impose a mA/watt specification that would require a power factor greater than 0.7 for all equipment regardless of its input power.

After discussing the basic requirements of the standard, the following paragraphs investigate in more detail the requirements of the standard concerning offline rectifiers.

*A. Applicable Standards*

The EN 61000-3-2 (IEC 1000-3-2) was first published as IEC 555-2:1982 and applied only to household appliances having an input current up to and including 16 A per phase. It was revised and reissued many times with the applicability expanded. The requirements for Testing and Measurement Techniques for this standard are found in IEC 61000-4-7. The EN 61000-3-2 standard also imposes stringent requirements on the power source’s voltage distortion level and regulation to being low, during measurements. The power source is not allowed to either contribute to or subtract from the current harmonics levels.

*B. Equipment Classifications / Limits*

The standard defines four different test classes, Class A, B, C, & D. Any equipment connected to the public utility grid in the European Union is covered in these four classes. Each class has its own set of limits for harmonic currents. A significant relaxation, present in the original standard, is that no limits apply (more correctly, limits are “under consideration”) for professional equipment with a power of more than 1kW. Also the class D “special waveshape” requirements in the original standard are effectively removed and so is the contentious issue of transition of the lower limit from 75 W to 50 W. This also means that a sinusoidal current would automatically meet the standard.

*Class A* – It is the “catch all” category. It includes motor driven equipment with phase angle control, most domestic” appliances, and virtually all three phase equipment ( $\leq 16$  A per phase). Anything that does not fit into the other three classes is also automatically categorized as Class A equipment. The limits are only defined for 230 V single phase and 230/400 V three-phase equipment. The maximum current allowed for each harmonic, to meet the Class A limits, is shown in Table 1.

*Class B* – This includes all portable tools. Harmonic current limits are absolute maximum values. As power tools are used infrequently/for short periods, so Class B limits are the least restrictive.

Class B limits are 1.5 times the Class A limits.

Table 1: EN 61000-3-2, Class A & Class D Harmonic Current limits

Harmonic order (n)	Class A	Class D	
	Absolute limit (No Power limit)	Relative limit (600W $\geq$ Power >75W)	Absolute limit (600W $\geq$ Power >75W)
	Maximum permissible harmonic current (A)	Maximum permissible harmonic current per watt (mA/W)	Maximum permissible harmonic current (A)
<b>Odd Harmonics</b>			
3	2.30	3.4	2.30
5	1.14	1.9	1.14
7	0.77	1.0	0.77
9	0.40	0.5	0.40
11	0.33	0.35	0.33
13	0.21		
15 $\leq n \leq 39$ (Class A)		Use following equations	
13 $\leq n \leq 39$ (Class D)	2.25/n	3.85/n	2.25/n
<b>Even Harmonics</b>			
2	1.08		
4	0.43		
6	0.30	Not Applicable	
8 $\leq n \leq 40$ (Class A)	1.84/n		

*Class C* – This includes all lighting products, including dimming devices, with an active input power higher than 25 W. There are limits on the second harmonics and also on all odd harmonics. The limits are expressed in terms of the fundamental current’s percentage. The maximum current percentage allowed for each harmonic, to meet Class C limits, is shown in Table 2. For active input power lower than 25 W, the mA/W related Class D limits become applicable or alternately the third harmonic current limits with some other specific conditions apply.

Table 2: EN 61000-3-2, Class C Harmonic Current limits

Harmonic order (n)	Maximum permissible harmonic current expressed as a percentage of the input current at the fundamental frequency
2	2
3	30 $\times$ circuit power factor
5	10
7	7
9	5
11 $\leq n \leq 39$	3

*Class D* – This class contains all equipment types that are under 600 W and are considered to have the greatest impact on the power network. These specifically include personal computers, their display monitors and TV receivers. To avoid any ambiguity arising due to the possible load variations of the equipment, the manufacturer is allowed to specify a power level for establishing the

limits, but this specified value must be within  $\pm 10\%$  of the actual measured value. The purpose of this approach is to prevent the situation in which equipment operating near the boundary and tested under slightly different conditions might be subject to widely differing limits. The specified power for this purpose is not necessarily the same as the manufacturer's 'rated' power for safety or functional purposes.

The current limits for Class D are expressed in terms of mA per Watt of power consumed and limited to an absolute value. The maximum relative permissible harmonic current limit per watt (mA/W) and the absolute current limit allowed for each harmonic, to meet Class D limits, is also shown in Table 1. Consequently, low power equipment has very low absolute limits of harmonic current.

In general the limits for Class A and Class B equipment are the easiest to meet. The pass/fail levels are fixed, irrespective of the power level of the equipment being tested. On the other hand, Class C and Class D limits are a lot more stringent because these products are found in greater volume. These limits also vary with the power level of the tested product. Other than the 2nd harmonic in Class C, there are no limits for even harmonics in Class C/D.

*C. The EN 61000 -3-2 and Offline rectifier circuits.*

Most Electronic/Electro-mechanical equipment have some kind of power converter built in, for power conversion purposes. As all electronic circuits work with dc, all power conversion circuits have a built in rectifier/filter circuit to operate from the utility network.

All power converters/offline rectifiers connected directly to mains network circuits will be classified as Class A/D. Those converters whose input current waveforms have high distortion and used more frequently or simultaneously by many, will tend to fall into Class D. Other converters with lesser current distortion are allowed for inclusion into Class A. It may appear from the above discussion that Class D limits are easier to meet, since it accepts current waveforms having higher distortion. However this is not true. Before explaining the advantage of being in Class A, a clearer understanding between Class A/D is provided.

Fig. 2 shows a representative difference between Class A and Class D current waveforms. The Class D waveform is that of an offline rectifier with capacitive filter. On modifying this current wave shape by incorporating some passive correction circuit / network, the earlier Class D waveform can be easily moved to Class A. This waveform is also shown in Fig. 2. Observe that for the same power rating, the Class A current waveform has a larger conduction angle, a lower peak current and a lower distortion.

The advantage of being in Class A is that at power levels less than approximately 600 W, the absolute limit for each

odd harmonic will be higher than that based on the mA/W limit calculated for Class D. Thus lower the power level, the greater will be this advantage of being in Class A.

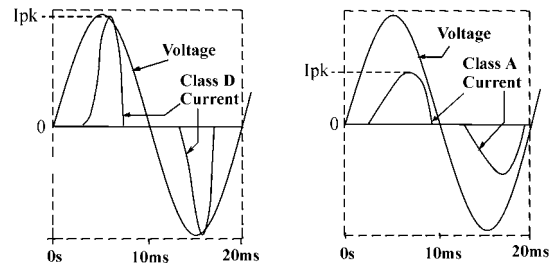


Fig. 2. Representative differences between Class D & Class A current waveforms.

Table 3 shows the comparison between the applicable absolute harmonic current limits for a 100 W converter applied to both the classes. Only odd order harmonic limits are shown, since off-line rectifier applications don't generate even order harmonics. The differences are large and this is clearly apparent.

Table 3: Class A versus Class D Odd Harmonic Current Limits

Harmonic Number	Fixed Class A Limits (A)	Class D limits (mA/W)	Class D Limits for 100W Input (A)
3	2.30	3.4	0.34
5	1.14	1.9	0.19
7	0.77	1.0	0.10
9	0.40	0.5	0.05
11	0.33	0.35	0.035
$13 \leq n \leq 39$	$0.15 \times 15/n$	$3.85/n$	$0.386/n$

*D. The 120 V/60 Hz Perspective.*

The standard discussed above refers to 230 V single phase and 230/400 V three-phase equipment. However the problems that necessitated the formation of this standard, are also prevalent with the 120 V system. Even though this standard does not directly fit into the 120 V system, the harmonic current limits for the 120 V system would be higher than the limits for the 230 V system. The third harmonic is higher by a scaling factor of 1.76 approximately. This was verified by PSpice simulations of a full-bridge diode rectifier circuit driving a 200 W constant power load from 120 V/60 Hz and 230 V/50 Hz ac input voltages respectively. The circuit is shown in Fig. 3a with  $L_S/R_S$  representing the mains network source impedance. To keep the dc ripple across  $C_O$  similar for both cases, a 470 mF capacitor was chosen for the 120 V / 60 Hz input while a 220 mF capacitor was chosen for the 230 V / 50 Hz input.

Typical values for  $L_S$  was chosen as 0.5 mH while  $R_S$  was chosen as 5 ohms. The simulation result of the harmonics is shown in Fig. 3b.

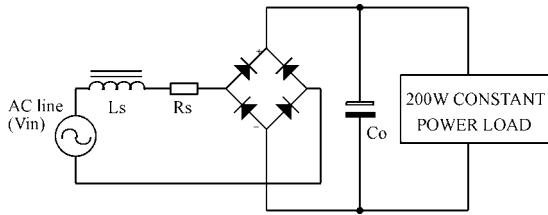


Fig. 3a. Single-Phase diode rectifier circuit with capacitive filter

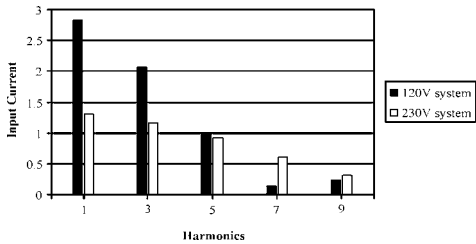


Fig. 3b. Simulation results of current harmonics for 120 V and 230 V system

### III. POWER FACTOR CORRECTION STRATEGIES

As the underlying cause of low power factor and high circulating currents created by switch mode power supplies is the discontinuous input-filter charging current, the solution lies in introducing elements to increase the rectifier's conduction angle. There are many approaches to mitigate this problem. These are namely the passive and active power factor correction, passive or active filtering in the network and lastly accepting a non-sinusoidal voltage/current in the system.

Most PFC topologies are limited to single-phase systems since most appliances are powered by a single-phase utility source. However three phase active PFC schemes like the Vienna rectifier [3] is also popular. The classification of various single-phase off-line PFC topologies is shown in Fig. 4. Among these PFC topologies, the passive, the low-frequency active and the high frequency active types are considered in this study.

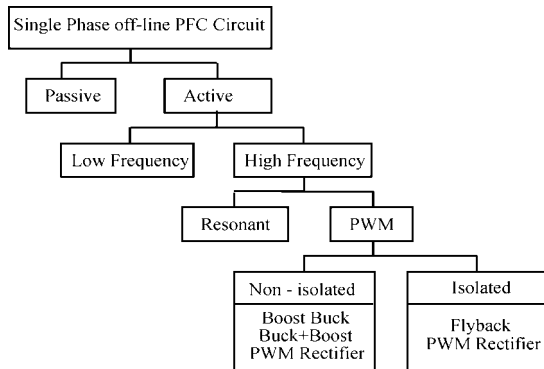


Fig. 4 Various Single-Phase off-line PFC topologies

#### A. Passive Power Factor Correction

Passive Power Factor correction is simply the use of an inductor in the input circuits. We used to call this an inductive input filter earlier. If the inductor is sufficiently large, it stores sufficient energy to maintain the rectifiers in conduction throughout the whole of their half cycle and reduces the harmonic distortion caused by discontinuous conduction of these rectifiers.

The inductors used in passive correctors are large and bulky, since they work at the mains frequency. For example, a 100 W SMPS would need an inductor of about 82 mH, to meet the EN 61000-3-2 Class A requirements. Moreover these inductors help meet the standard by reducing the unwanted harmonic currents substantially. Some serious disadvantages of a series inductor is the losses due to its resistance, risk of resonance with the filter capacitor and voltage at the load may be lower due to the voltage drop in the inductor. This voltage drop is mainly because the current in the inductor is continuous for a longer period. Fig. 5a shows the simplified block diagram of a passive power factor correction circuit while Fig. 5b shows the representative input voltage & current waveforms.

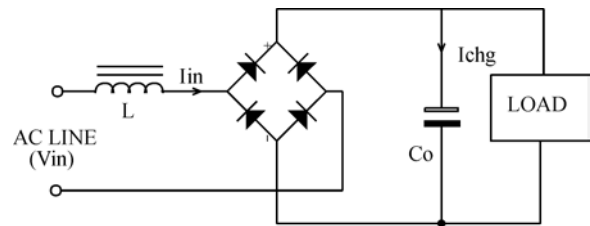


Fig. 5a. block diagram of a passive power factor correction circuit

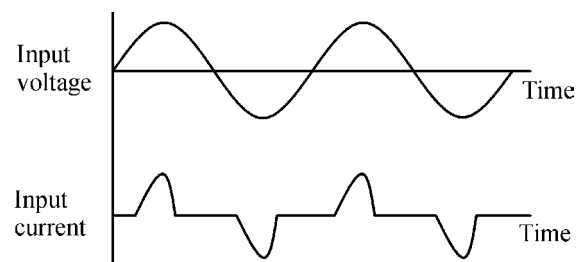


Fig. 5b. Input Voltage & Current waveforms of a Passive PFC circuit

A practical passive PFC reduces the harmonic currents and improves the power factor substantially, but it does not eliminate the problem completely.

Let us take the example of a 200 W power supply operating from the 230 V ac line. The third harmonic current drawn by a switch mode power supply without power factor correction is typically 82 percent of the fundamental

current while it's power factor would be 0.65. This means an uncorrected switch mode power supply drawing 200 watts from the ac line will have a third harmonic current of about 1.09Amps  $\{(0.82 \times 200 \text{ W}) / (230 \text{ V} \times 0.65)\}$  and that exceeds the Class D limit of 0.68 A (3.4 mA x 200 W). The same power supply could have had the same third harmonic current when operating as a Class A equipment. To qualify for Class A status, the rectifier must conduct for a longer period. A 315-degree conduction angle yields a power factor between 0.85 and 0.90 and this is significantly higher than the 0.65, which is typical of an uncorrected switcher.

Therefore most power supply manufacturers presently find it more convenient and economical to meet the standard, by putting a small inductor in series to the input circuit. This inductor changes the input current wave shape and moves an equipment from the difficult to meet Class D limit to the easier to meet Class A limit. However, when power ratings are more than 300 W, the cost and size of this inductor becomes unjustifiable and an active power factor correction front-end circuit becomes the most practical alternative. PSpice simulation of a full-bridge diode rectifier/capacitive filter circuit driving a constant power load of 200 W and an optional inductor of 82 mH, can verify this. The circuit is similar to that shown in Fig. 5a and operates from a 230 V ac input. The simulation result of the input current with and without the inductor, is shown in Fig. 6. Observe as to how the input current waveform changes in amplitude and conduction angle, on connecting the inductor in the input circuit.

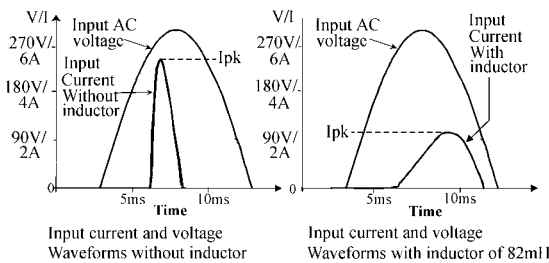


Fig. 6. 200 W rectification, Simulation results of the input without and with inductor.

Fig. 7a shows the experimental setup to record the input current of two identical 200 W switch mode power supplies, that are switched on alternately. For one power supply the input is uncorrected while for the other input correction is done by putting a 70mH inductor in the input circuit. The input current for the power supply without correction is shown in the oscillogram of Fig. 7b while Fig. 7c shows the input current for the power supply with the inductor. For both oscillograms Channel 1 shows the input voltage while Channel 2 shows the input current. The measurements show the peak current amplitude values.

The passive PFC has the advantage of being extremely reliable when compared to the active PFC solutions, as it

uses much less number of components. However, to keep the power factor good at lower output power conditions, the passive PFC requires a larger inductance at lower powers when compared to the inductance requirements at higher output powers. This can be verified by PSpice simulation of a full-bridge diode rectifier circuit driving a constant power load of 200 W/30 W with passive PFC circuit. The simulation result shown in Fig. 8a, shows the input current for a fixed inductor value of 82mH. Observe as to how the input current waveform's conduction angle reduces, on reducing the output power to 30W.

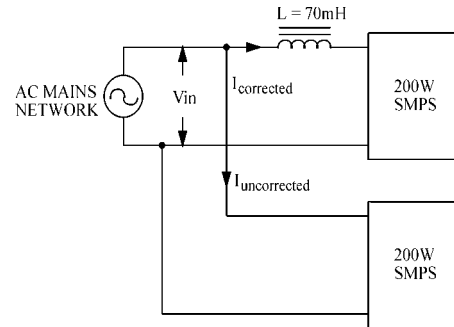


Fig. 7a. Experimental setup to measure the input current of a SMPS with and without an inductor in the input circuit

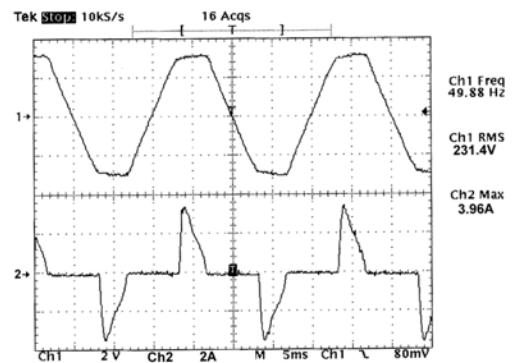


Fig. 7b. Oscillogram showing the input current for an un-corrected power supply.

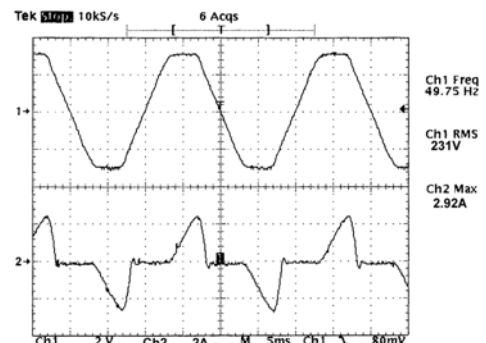


Fig. 7c. Oscillogram showing the input current for a power supply with a 70 mH PFC inductor at the input.

It is apparent from the above simulation that for a variable load, the inductance should also be variable or alternately the inductor value should be designed for 30 W while its copper/core size should be for 200 W. This naturally makes the inductance very large and expensive.

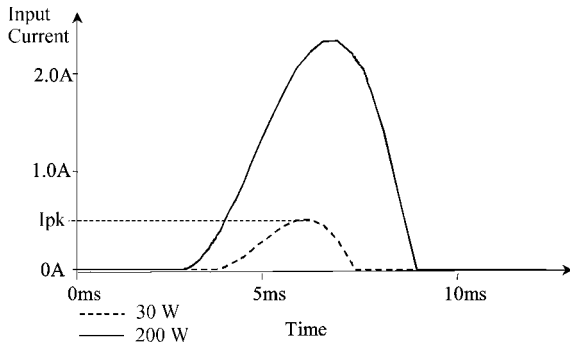


Fig. 8a. Simulation results of input currents for loads of 30 W & 200 W with fixed inductance value

The easiest way to overcome this problem is to use a swinging choke [4]. This is done, as shown in Fig. 8b, by using a wedge shaped airgap in the inductor. This gives a high inductance for lower currents and a lower inductance for higher currents. As current increases, the core progressively saturates from the end where the airgap is minimum. The minimum air gap is shown as D2 and the maximum air gap as D1.

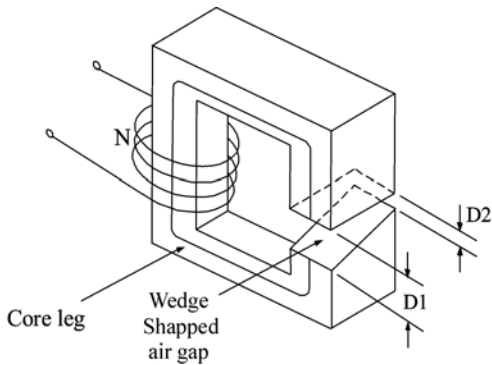


Fig. 8b. Construction of a swinging inductor

The input current for a power supply with a swinging inductor and output load of 200 W is shown in the oscillogram of Fig. 9a. Fig. 9b shows the input current for the same power supply with the output load set to 40 W. For both oscillograms Channel 1 shows the input voltage while Channel 2 shows the input current. The measurements show the peak current amplitude values. The inductor had an inductance of 170 mH at zero bias. The minimum air gap D2 was 0.1mm while the maximum air gap D1 was 6.5 mm. The size of this swinging inductor is similar to the 70 mH inductor of Fig. 7.

Thus with the given advantages and disadvantages of the passive PFC, it apparently is the best solution to meet the EN 61000-3-2 requirements for power levels up to 300 W.

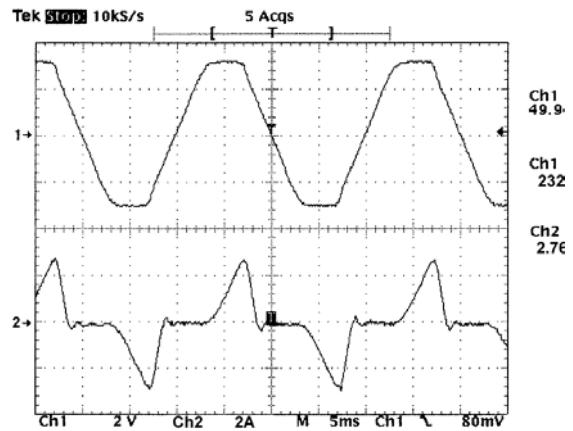


Fig. 9a. Oscillogram showing input current for a 200 W corrected power supply with a 170 mH swinging inductor at the input.

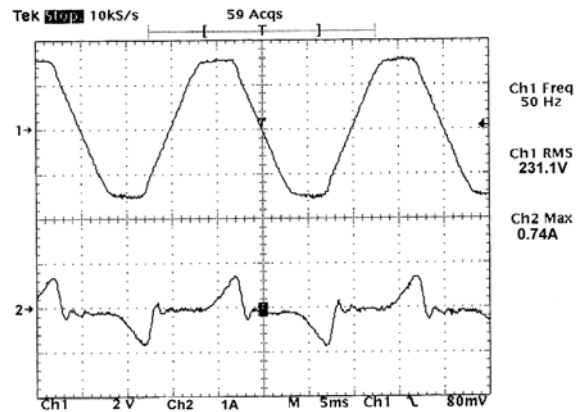


Fig. 9b. Oscillogram showing input current for the same corrected power supply with the 170 mH swinging inductor and output set to 40 W.

*B. Low frequency active Power Factor Correction*

An active low frequency approach can be implemented up to about 1000 watts. Fig. 10 shows a typical design [5] and the input current waveform. Power factors as high as 0.95 can be achieved with an active low frequency design.

In this scheme the switch (SW) is bi-directional and is operated just twice per line period. The switch opens after a fixed constant time period or when the output “dc” is higher than the set value. The corresponding current drawn by the line is shown in Fig. 10b. The switch is turned on for a constant period after the zero crossing of the line voltage. The output dc voltage commands the switch turn off, when the instantaneous switch current reaches a

suitable reference value, thus allowing a simple current limiting protection to be implemented. During the on time, which is relatively short as compared to the line half-period, the inductor current increases almost linearly. The current slope is determined by the instantaneous input voltage and by the inductor value. As the switch turns off, the voltage across the filter inductor adds to the instantaneous input ac voltage and generates a boosted voltage across the output capacitor. This forces an increase in the conduction angle of the input bridge rectifiers, giving rise to the current waveform shown in Fig. 10b. The output voltage is now stabilized at about 400 V and the inductor voltage drop is compensated by the boost effect of this circuit.

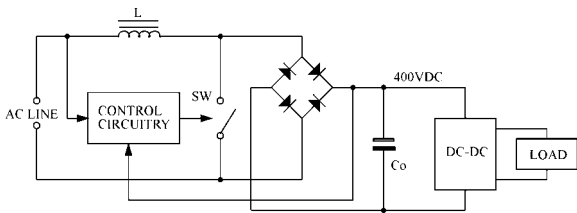


Fig. 10a. Low frequency active power factor correction circuit

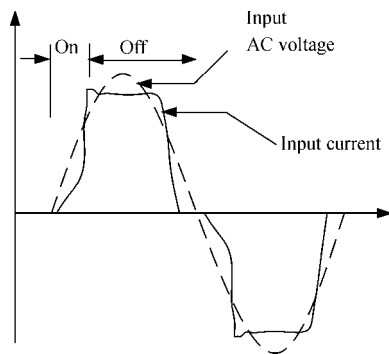


Fig. 10b. Input current waveform of a low frequency active power factor correction circuit

This scheme has the advantage that it generates less EMI, requires a smaller inductor when compared to the passive PFC and the simple low frequency circuit is more reliable and efficient when compared to the active high frequency PFC scheme. However with the inductor's operation at the line frequency, its size and weight will limit the usefulness of this topology above 1 kW. An extensive discussion on the advantages and other low frequency PFC schemes is provided in [6].

C. High frequency active Power Factor Correction

Active high frequency power factor correction makes the load behave like a resistor leading to near unity load power factor and the load generating negligible harmonics. The input current is similar to the input voltage waveform's waveshape. High Frequency active power factor correction can be made in ways that are consistent with the goals of switch mode conversion (small size and lightweight). A

variety of topologies [7] can be used including the boost converter and the buck converter. For reasons of simplicity and it's popularity, the boost [8] converter is described here. The flyback PWM converter providing power factor correction, is limited to power levels of about 100 W. This topology is popular for it's ability to provide isolated output and power factor correction using a single conversion level. The boost converter on the other hand can be designed to power levels of 5000 W and more. However as it provides a stepped up non-isolated dc output, a down stream dc-dc converter is always necessary to generate an isolated dc output.

Fig. 11 shows the simplified block diagram of an active power factor correction circuit.

As its name implies, a boost converter produces an output voltage higher than its input. This enhances the energy storing function of the filter capacitor,  $C_o$ . Also, with careful design, a boost converter can provide a relatively stable output over a wide range of input voltages. The power factor correcting boost converter produces a constantly high voltage across its output capacitor, regardless of the input mains voltage. Thus the hold up time becomes independent of the mains voltage.

The circuit functions by monitoring the input full wave rectified line voltage wave shape, the magnitude of the input voltage average and the output voltage. These three input signals are combined to modulate the average input current waveform in accordance with the rectified line voltage, while regulating the output voltage for line and load variations. The boost regulator's input current is

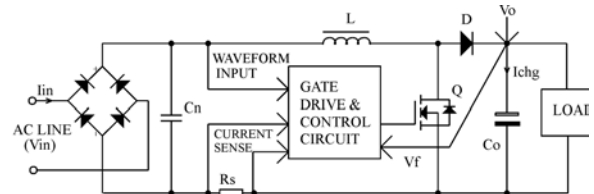


Fig. 11. Block diagram of an active power factor correction circuit

forced to be proportional to the input voltage waveform by modulating the boost regulator's mosfet drive, for power factor correction. To control the input current, either peak current mode control or average current mode control may be used. The oscillogram in Fig. 12 shows the measurements of the input current of a 600 W average current mode controlled power factor correction circuit, switching at 50 kHz. Channel 1 of the oscillogram shows the input voltage while Channel 2 shows the input current. The measurements show the RMS and peak amplitude current values.

This Power Factor Correction control circuit controls the current through the boost inductor by pulse width modulated pulses. The operating frequency is selected to be

high enough to maintain the inductor current in continuous mode, thus making the inductor a controlled current source. By using the rectified source voltage waveshape as reference, the inductor current, which is the current drawn from the source, is forced to be sinusoidal and in phase with the source voltage, thus maintaining high power factor.

Operation of the converter's voltage stabilization loop controls the boost inductor current. The source current is thus defined by the need to keep the filter capacitor's

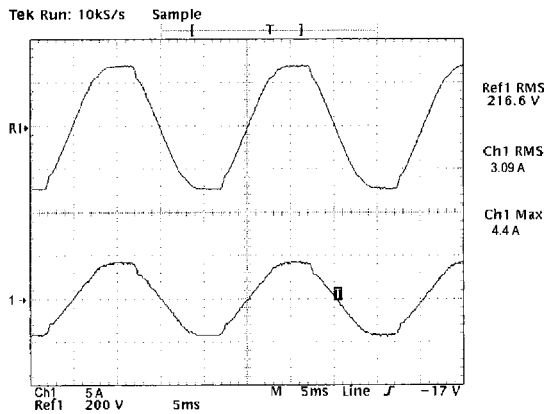


Fig. 12. Input current waveform of a 600W average current mode controlled active PFC circuit

voltage constant, at about 385 volts, in the face of varying ac input, dc load, set point etc.

The PWM strategy for the boost converter used for high frequency power factor correction scheme described above, could be either hard switched or resonant mode conversion. Integrated circuits providing complete control solutions, in hard switching or resonant mode conversion, have been commercially available for sometime. Probably the first commercial power factor correction controller IC, that is popular even today, was the UC3854 [9] from the erstwhile Unitrode Corporation. Subsequently many other control IC's have followed, including the resonant mode power factor correction IC, the UC3855. Of late a lot of work has been done on digital control techniques [10] for high frequency active power factor correction. Probably one of the first commercial digital power factor correction controller IC is the IW2202 from IWatt Corporation.

#### IV. CONCLUSION

In this paper the various applicable low frequency harmonic current limits and classes set forth by the EN 61000-3-2 standard, particularly in consideration to offline rectifier applications, is studied.

The advantages and disadvantages of having a passive PFC for Offline Rectifier Applications, to meet the mandatory EN 61000-3-2 standard, is highlighted. Other popular

power factor schemes, their advantages and disadvantages are also explored in this paper.

This paper will not put an end to the discussion concerning the harmonic standard, but it does offer a number of solutions for equipment to comply with the standard. We thus conclude that having to run all home and office equipment that meet the mandatory EN 61000-3-2, has many advantages that far outweigh the traditional difficulty of higher equipment costs.

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