Critical Analysis of Power Factor Improvement of Single Phase AC/DC Converter by Passive/Active Filters

Ms. Snehal B. Gatkine[1], Dr. Hari Kumar Naidu[2], Vaishali Pawade[3]
[1]PG Scholar, [2]HOD, [3]AP
Electrical Engineering, Tulsiramji Gaikwad-Patil College of Engineering and Technology
Nagpur, Maharashtra, India

ABSTRACT

This paper provides a concise review of the most interesting passive and active filters of power factor correction, for single phase and low power applications. The increasing growth in the use of electronic equipment in recent years has resulted in a greater need to ensure that the line current harmonic content of any equipment connected to the ac mains is limited to meet regulatory standards. This requirement is usually satisfied by incorporating some form of Power Factor Correction (PFC) circuits to shape the input phase currents, so that they are sinusoidal in nature and are in phase with the input phase voltages. There are multiple solutions in which line current is sinusoidal. The major advantages and disadvantages are highlighted.

Keywords: *Converter, Power factor correction, Harmonic Current*

1. INTRODUCTION

Power factor correction (PFC) is necessary for ac-to-dc converters in order to comply with the requirements of international standards, PFC can reduce the harmonics in the line current, increase the efficiency and capacity of power systems, and reduce customer's utility bill Single phase diode rectifiers are widely used for industrial applications. Many conventional switching power supplies in data processing equipment and low power motor drive systems operate by rectifying the input ac line voltage and filtering with large electrolytic capacitors. The capacitor draws current in short pulses. This introduces several problems including reduction in the available power and increase losses. This process involves both nonlinear and storage elements, and results in the generation of harmonics in the line current [3-5].The non linear characteristics of loads such televisions, computers, faxes and variable speed motor drives (used in air-conditioning) have made harmonic distortion in electrical distribution systems. However, when operating in large numbers, the cumulative effect of these loads has the capability of causing serious harmonic distortions. This results in a poor power quality, voltage distortion, poor power factor at input ac mains, slowly varying rippled dc output at load end and low efficiency [3]. The input current has narrow pulses which in turn increase its RMS value. Buildings with a large number of computers and data processing equipments also experience large neutral current. The non-ideal character of these input currents creates a number of problems for the power distribution network and for other electrical apparatuses in the neighborhood of the rectifier systems. This approach has many disadvantages, including:

1. High-input harmonic current components.
2. Low rectifier efficiency due to large rms value of the input current.
3. Input ac mains voltage distortion because of the associated current.
4. Maximum input power factor is approximately 0.6, while a larger filter inductor is required for a high-input power factor [4].

Unless some correction circuit is used, the input rectifier with a capacitive filter circuit will draw pulsating currents from the utility grid, resulting in poor power quality and high harmonic contents that

adversely affect other users. The situation has drawn the attention of regulatory bodies around the world. Governments are tightening regulation, setting new specifications for low harmonic currents, and restricting the amount of harmonic currents that can be generated. As a result, there is a need for a reduction in line harmonics current necessitating the need for power factor correction (PFC) and harmonic reduction circuits [5]

2. Definition of Power Factor

Power factor (PF) is defined as the ratio of the real power (P) to apparent power (S), or cosine (for pure sine wave for both current and voltage) the phase angle between the current and voltage waveforms.

PF = Real Power / Apparent Power (1)

Real power (watts) produces real work; this is the energy transfer component. Reactive power is the power required to produce the magnetic fields (lost power) to enable the real work to be done, where apparent power is considered the total power that the power company supplies. This total power is the power supplied through the power mains to produce the required amount of real power.

If both current and voltage are sinusoidal and in phase, the power factor is 1.0. If both are sinusoidal but not in phase, the power factor is the cosine of the phase angle. In elementary courses in electricity, this is sometimes taught as the definition of the power factor, but it applies only in the special case, where both the current and voltage are pure sine waves. This occurs when the load is composed of resistive, capacitive and inductive elements and all are linear (invariant with current and voltage)
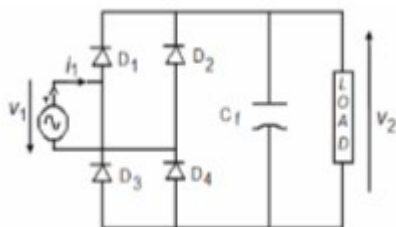

Fig 1.Diode Bridge Rectifier

Switched-mode power supplies present a non-linear impedance to the mains, as a result of the input circuitry. The input circuit usually consists of a half-wave or full-wave rectifier followed by a storage capacitor (similar to Fig. 1).

The capacitor maintains voltage of approximately the peak voltage of the input sine wave until the next peak comes along to recharge it. In this case, current is drawn from the input only at the peaks of the input waveform, and this pulse of current must contain enough energy to sustain the load until the next peak. This is done by dumping a large charge into the capacitor during a short time, after which the capacitor slowly discharges the energy into the load until the cycle repeats. It is not unusual for the current pulse of 10% to 20% of the cycle duration, meaning that the current during the pulse must be 5 to 10 times of the average current as illustrated by fig. 2
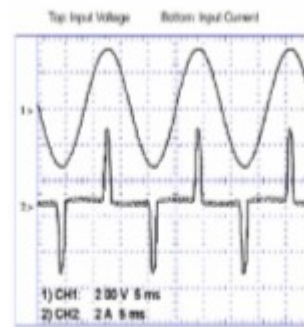

.Fig 2 Input Characteristics of a Switched Mode Power Supply without PFC

3. Power Factor Correction Circuit

The classification of single-phase PFC topologies is shown in Fig.3 The diode bridge rectifier (similar to Fig. 1) has no sinusoidal line current. This is because most loads require supply voltage V_2 with low ripple, which is obtained by using a correspondingly large capacitance of the output capacitor C_f. Consequently, the conduction intervals of the rectifier diodes are short and the line current consists of narrow pulses with an important harmonic contents [8]. There are several methods to reduce the harmonic contents of the line current in single-phase systems:
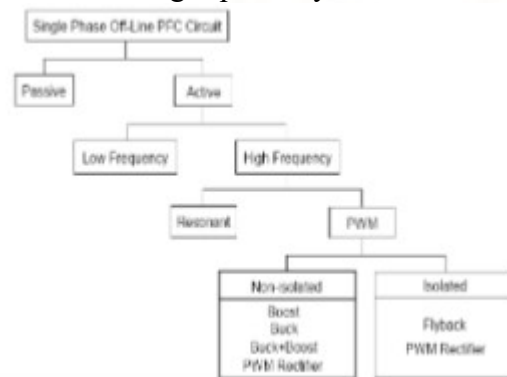

Fig 3 Classification of Single Phase PFC Topologies

3.1 Passive Methods of PFC:-

3.1.1 Rectifier with series-resonant band-pass filter

The shape of the line current can be further improved by using a combination of low-pass input and output filters [10]. There are also several solutions based on resonant networks which are used to attenuate harmonics. For example, a band-pass filter of the series resonant type, tuned at the line-frequency, is introduced in-between the AC source and the load. Figure (a) shows the schematic diagram, and figure (b) shows the simulated results. For 50Hz networks, large values of the reactive elements are needed.

(a)

(b)

Fig.3.1.1 Rectifier with series-resonant band-pass filter: a) Schematic; b) Line voltage and line current with V_1=220V_{rms}; resistiv load R=500Ω; C_f=470µF, Ls=1.5H and Cs=6.75 µ F

3.1.2 Rectifier with parallel-resonant band-stop filter

The solution uses a band-stop filter of the parallel resonant type [4]. Figure 3.1.2 shows the schematic diagram and the simulated waveforms. The filter is tuned at the third harmonic, hence it allows for lower values of the reactive elements when compared to the series-resonant band-pass filter.
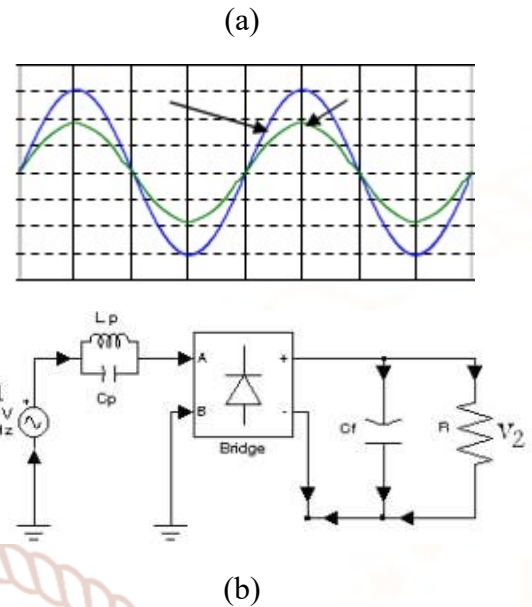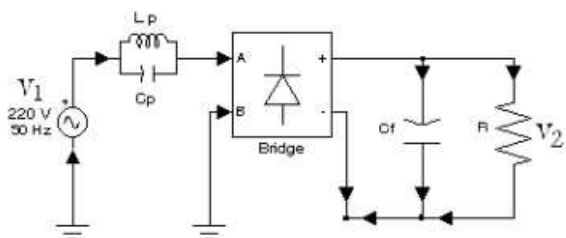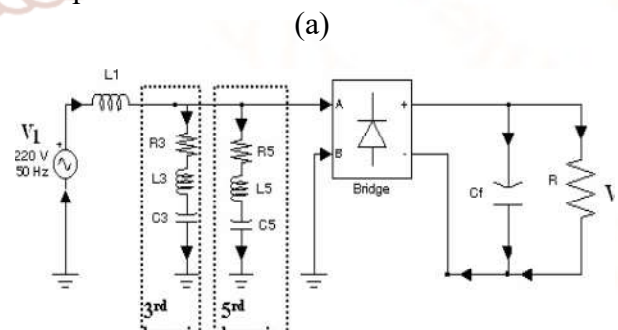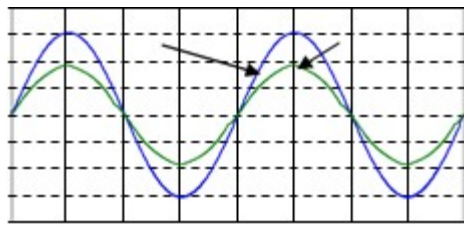

(a)

(a)

(b)

Fig. 3.1.2- Rectifier with parallel-resonant band-stop filter: a) Schematic; b) Line voltage and line current with V1=220Vrms, resistive load R=500Ω , C_f=470µF, L_p=240mH and C_p=4.7 µF.
The line current has K_d=0.919, cos φ=0.999 and PF=0.918, and output voltage V_2 = 260 V.

3.1.3 Rectifier with harmonic trap filter

Another possibility is to use a harmonic trap filter. The Harmonic trap consists of a series-resonant network, connected in parallel to the AC source and tuned at a harmonic that must be attenuated [11]. For example, the filter shown in Fig. 8 has two harmonic traps, which are tuned at the 3rd and 5th harmonic, respectively. As seen from Fig. 9 (b), the line current is improved, at the expense of increased circuit complexity. Harmonic traps can be used also in conjunction with other reactive networks, such as a band-stop filter.

(a)

(b)

Fig. 3.1.3- Rectifier with harmonic trap filter: a) Schematic; b) Line voltage and line current
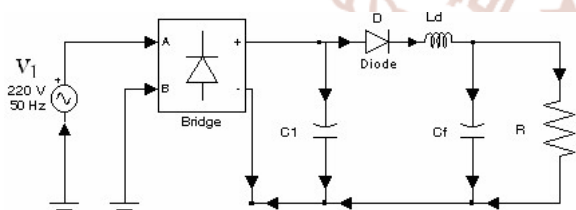
In Fig.9, with V_1=220Vrms, resistive load R=500Ω , C_f=470μF, L1=400mH , L3=200mH , C3=5.6 μF , R3=0.1 Ω , L5=100mH , C5=4.04 μF , and R5=0.1 Ω; The line current has K_d=0.999, cos φ=0.999 and PF=0.998, and output voltage V_2=290V

3.1.3. Rectifier with an additional inductor, capacitor and diode (LCD):-

The rectifier with an additional inductor, capacitor, and diode – LCD rectifier – is shown in Fig. 10, together with simulated waveforms. The added reactive elements have relatively low values. The circuit changes the shape of the input current, while only a limited reduction of the harmonic currents can be obtained.

In3.1.3, with V1=220Vrms, resistive load R=500Ω , Cf=470μF, C1=40 μF and Ld=10mH ; The line current has Kd=0.794, cos φ=0.998 and PF=0.792, and output voltage isV2=300V.
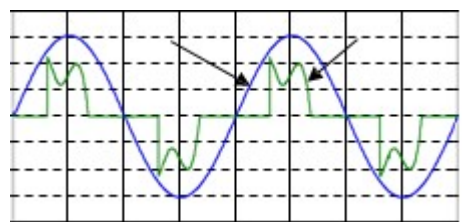
(a)

(b)

Fig. 3.1.4 Rectifier with an additional inductor, capacitor and diode (LCD) a) schematic diagram ; b) Line voltage and line current.

Passive methods of power factor correction have certain advantages, such as simplicity, reliability and ruggedness, insensitivity to noise and surges, no generation of high frequency Electro Magnetic Interface (EMI) and no high frequency switching losses. On the other hand, they also have several drawbacks. Solutions based on filters are heavy and bulky, because the line-frequency reactive components are used. They also have a poor dynamic response, lack voltage regulation and the shape of their input current depends on the load.. Even though line current harmonics are reduced, the fundamental component may show an excessive phase shift that reduces the power factor. Moreover, circuits based on resonant networks are sensitive to the line-frequency. In harmonic trap filters, series-resonance is used to attenuate a specific harmonic. However, parallel-resonance at different frequencies occurs too, which can amplify other harmonics.
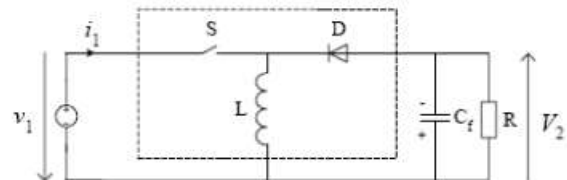
3.2 Active Method of PFC:-
The active methods of PFC, which involve the shaping of the line current, using switching devices such as MOSFETs and IGBTs, is a result of advances in power semiconductor devices.
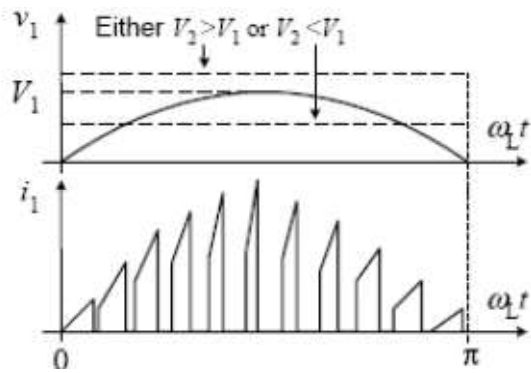
3.2.1. High Frequency Active Method of PFC:-
The PFC stage can be realized by using a diode bridge and a DC/DC converter with a switching frequency much Higher than the line-frequency. In principle, any DC/DC converter can be used for this purpose, if a suitable control method is used to shape its input current, or if it has inherent PFC properties . The converters can operate in Continuous Inductor Current Mode – CICM, where the inductor current never reaches zero during one switching cycle, or Discontinuous Inductor Current Mode - DICM, where the inductor current is zero during intervals of the switching cycle.
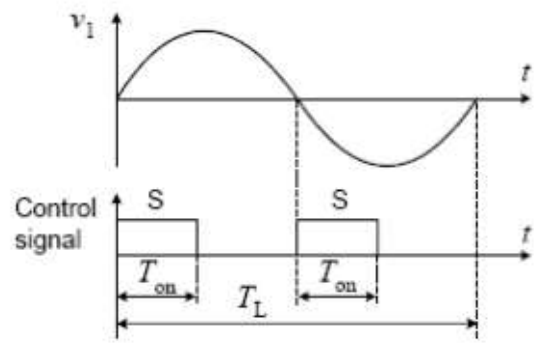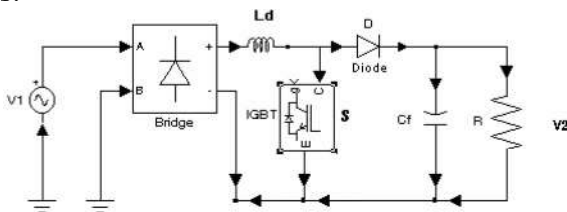

(a)

(b)

Fig 3.2.1 (a) Buck-Boost Converter with (b) Waveforms
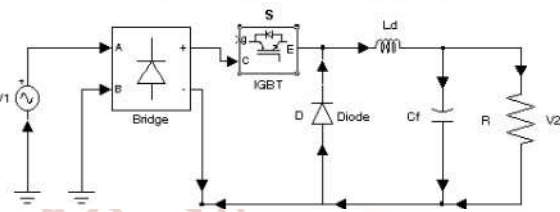
3.2.2 Low Frequency Active Method of PFC

The low-frequency switching Boost converter is shown in Fig.3.2.2 (a) The active switch S is turned on for the duration *Ton*, as illustrated in Fig., to enlarge the conduction interval of the rectifier diodes [2]. It is also possible to have multiple switching per half line-cycle, at low switching frequency, in order to improve the shape of the line current [15]. Nevertheless, the line current has a considerable ripple content.

The low-frequency switching Buck converter is shown in Fig. (b). Theoretically, the inductor current is constant for a near-infinite inductance L_d. The switch is turned on for the duration *T*on and the on-time intervals are symmetrical with respect to the zero-crossings of the line voltage, as illustrated in Fig.11(c). The line current shape is square, with adjustable duty-cycle. For lower harmonic contents of the line current, multiple switching per line-cycle can be used. However, the required inductance *L*d is large and impractical .
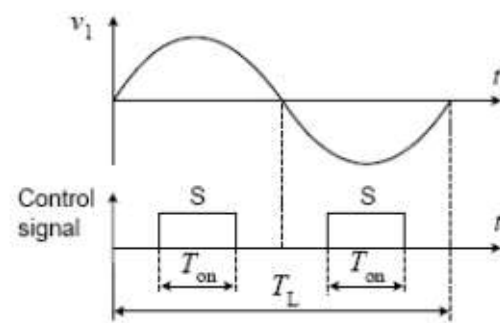
To conclude, low-frequency switching PFC offers the possibility to control the output voltage within certain limits.

(a)

(b)

(c)

(d)

To conclude, low-frequency switching PFC offers the possibility to control the output voltage within certain limits .In such circuits, switching losses and high-frequency EMI are negligible. However, the reactive elements are large and the regulation of the output voltage is slow.

4.PWM Rectifier:-

Another non-isolated PFC topology is the PWM rectifier , shown in Fig.4. The topology in Ref [3] can supply the step-up or step-down outputs like the buck-boost circuit. A full-bridge PWM rectifier in Ref [4] provides the step-up output. The PWM rectifier circuit needs two [3] or four [4] power switches to achieve the unity power factor, because it employs a half- or full-bridge configuration. It also needs more complicated control than the boost topology.
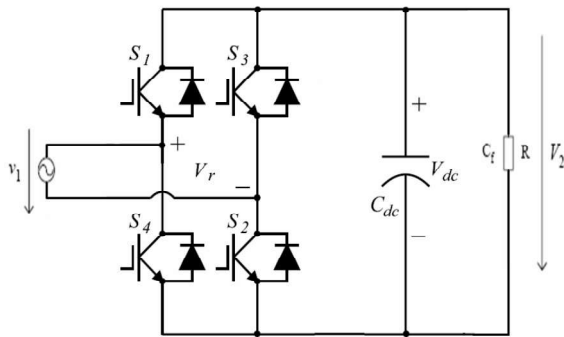
Fig 4 . PWM Rectifier

The use of active techniques of PFC results in one or more
of the following advantages:
➢ Lower harmonic contents in the input current in
➢ comparison to the passive techniques.
➢ Reduced r.m.s current rating of the output filter capacitor.
➢ Unity power factor is possible to achieve.
➢ For higher power levels, active techniques of PFC will result in size, weight and cost benefits over passive techniques of PFC.

5.Conclusion

As we have seen, conventional AC rectification is a very inefficient process, resulting from a waveform distortion of the current drawn from the power line. It produces a large spectrum of harmonic signals that may disturb other equipments.

It is concluded that the harmonics may be reduced and the supply can be mad more efficient by additional circuits at the input of the converter.

Many solutions for ac-dc power factor correction have been discussed. Examples have been provided for passive techniques. Passive power factor correction circuits have certain advantages, such as simplicity, reliability and ruggedness, insensitivity to noise and surges, no generation of high-frequency EMI and no high frequency switching losses.

On the other hand, they also have several drawbacks. Active PFC solutions are more suitable options for achieving near unity power factor and sinusoidal input current waveform with extremely low harmonic distortion. In these active solutions, a converter with switching frequencies higher than the AC line frequency is placed in between the output of the diode bridge rectifier and the bulk capacitor. The reactive elements of this converter are small, because their size depends on the converter switching frequency rather than the AC line frequency.

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