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A Variable Switching Frequency with Boost Power Factor Correction Converter

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Abstrak

Makalah ini menghadirkan koreksi faktor daya (PFC) phase tunggal dengan suatu teknik kendali frekuensi penyaklaran variabel (VSF). Peningkatan beban non linier seperti penyearah thyristor, catu daya mode penyaklaran, pengemudian kecepatan yang dapat diatur, dan pembangkit arus harmonik menyebabkan berbagai masalah terhadap perangkat lain yang ke titik kopling bersama. Ada beberapa kelemahan pada implementasi kendali PFC berbasis kendali PWM konvensional yang telah ada. Sistemyang diusulkan dianggap menggunakan penyelesaian kompak untuk mengatasi sebuah kelemahan dengan mengkonversi sumber tegangan ke sumber arus aksi cepat, yang mengurangi harmonisa pada arus fasa, meningkatkan efisiensi dan kapasitas sistem tenaga listrik. Kapasitor dan induktor dengan riak tegangan dan arus minimal dirancang untuk menyerap arus masukan sinusoidal dan untuk mengurangi distorsi harmonik total (THD) pada arus keluaran dengan regulasi tegangan keluaran. Prinsiip operasi, analisis teoritis, hasil simulasi pada boost konverter satu fasa disajikan.

Kata kunci: *desain dan pemodelan PFC, kendali tegangan, THD, topologi boost, VSF*

Abstract

This paper presents single phase Power Factor Correction (PFC) with proposed variable switching frequency (VSF) control technique. The increasing of non linear loads such as thyristor rectifiers, switching-mode power supplies, adjustable speed drives, and generate harmonic currents causing various problems to the other equipment connected to the point of common coupling. There are several disadvantages in the existing PFC control implementation based on conventional PWM control. This system considered uses a unified overcomes such a drawback by converting a voltage source into a fast-acting current source, which is reduce the harmonics in the line current, increases the efficiency and capacity of power system. The capacitor and inductor with voltage and current ripple with minimum ripple values was designed to absorb sinusoidal input current and to reduce total harmonic distortion (THD) in the input current with output voltage regulation. The principal of operation, theoretical analysis, simulation results on a single phase boost converter are presented.

Keywords: *boost topology, control technique, design and modeling of PFC, THD, VSF*

1. Introduction

In recent years, single phase switch-mode AC-DC power converters have been increasingly used in the industrial, commercial, residential, aerospace, and military environment due to the advantages of high efficiency and smaller size and weight. However, the proliferation of the power converters draw pulsating input currents from the utility line; this not only results in poor input power factor of the converters but also injects a significant amount of harmonic current into the utility line. Regarding the power factor correction stage, the boost converter is widely used because of its advantages: grounded transistor, small input inductor, simplicity high efficiency and the boost inductor is in series with the ac power line. This results in the minimum conducted EMI at the line when the circuit operates in continuous conduction mode.

In conventional techniques, input voltage is assumed to be sinusoidal. But, this voltage is not a sinusoidal all time. Due to existing of nonlinear loads in the distributed system the input voltage of the rectifier may be distorted and not have a sinusoidal waveform. So, the ac input current controlled by the controller will have the same wave shape of the input voltage which is not sinusoidal and includes harmonics. The boost inductor stores only a part of the transferred energy (because the mains still supplies energy during the inductor demagnetization) and so

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the required inductor is smaller comparing with the other topologies [3]. Hysteresis current control scheme is used due to its better performance in obtaining a sinusoidal input current. Its advantages are no need of compensation ramp and low distorted input current waveforms. According to this control technique, the switch is turned on when the inductor current goes below the lower reference and is turned off when the inductor current goes above the upper reference giving rise to a variable frequency control [4]. In this paper the hysteresis current control technique is investigated. The model of the system is derived and simulated by MATLAB/Simulink.

2. The Proposed System

2.1 System Configuration

2.1.1 Voltage Control Loop

The error is estimated from the DC output voltage measurement. The DC output voltage control loop maintains the capacitor voltage at a set reference value using feedback action. The error at the DC output is regulated by a PI controller (voltage compensator or Integrator) and the PI controller output is added to the current control loop to vary the duty ration to maintain the DC output voltage.

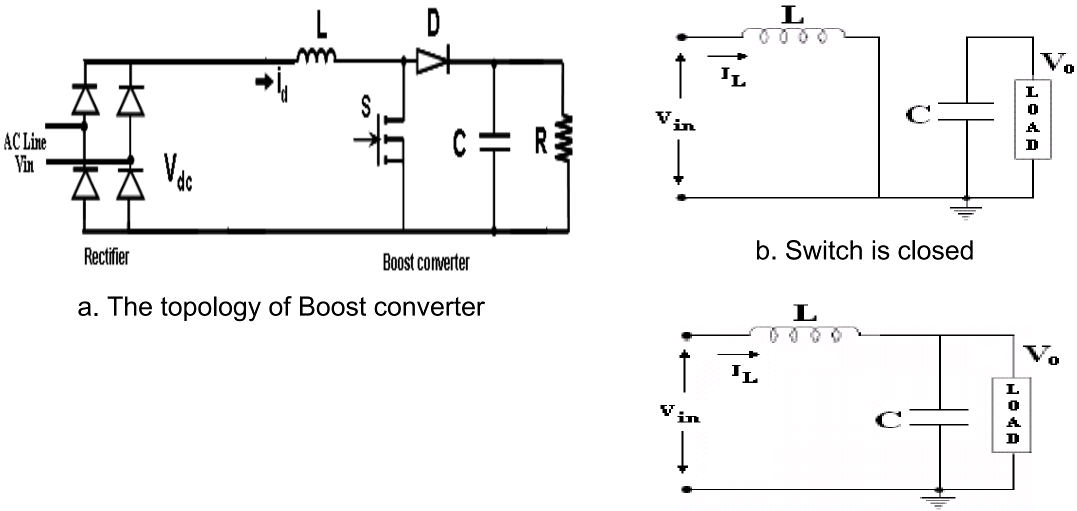
2.1.2 Current Control loop

The current control techniques have gained importance in ac to dc converters used for high performance applications [1]. Where, the fast response and high accuracy are important. Various current control methods have been proposed and classified as hysteresis control, predictive control, linear control and timer controller with constant switching frequency. Principle of these methods are briefly described and discussed below.

2.1.3 System Description

The topology of Boost converter is shown in Figure 1a.

(a) Boost converter operates at continuous conduction mode.
(b) The switching frequency is much higher than the line frequency.



a. The topology of Boost converter

b. Switch is closed

c. Switch is open

Figure 1. Basic Boost Converter with uncontrolled bridge rectifier

When ‘S’ Closed: in this mode of operation the switch is in on state. In this mode (Figure 1b), the current flows through switch and inductor, so the energy is stored to the inductor. At the same time, the capacitor discharges and supplies current to the load. When ‘S’ Open: in this mode of operation the switch is in off state and current flows through inductor, diode, the capacitor together with the load, and return to main. Mode 2 is shown in Figure 1c.

2.2 Proposed Variable Switching Frequency Technique

Figure 2 shown the schematic diagram of the hysteresis control circuit. As seen, the control method has two loops, the current control loop and the voltage control loop. Two sinusoidal current references I_{refp} sinωt, I_{refV} sinωt are generated one for the peak and other for the valley of the inductor current .According to this control technique the switch is turned on when the inductor current goes below the lower reference I_{refV} sinωt and is turned off when the inductor current goes above the upper reference I_{refp} sinωt giving rise to variable frequency control as shown in Figure 2. Also with this control technique the converter works in continuous inductor current mode (CICM).The inductor current ripple is δsinωt, where δ is the peak current ripple. Since the inductor current switches at a much higher rate then the line voltage, the line voltage i_o assumed constant in each inductor current switching cycle.

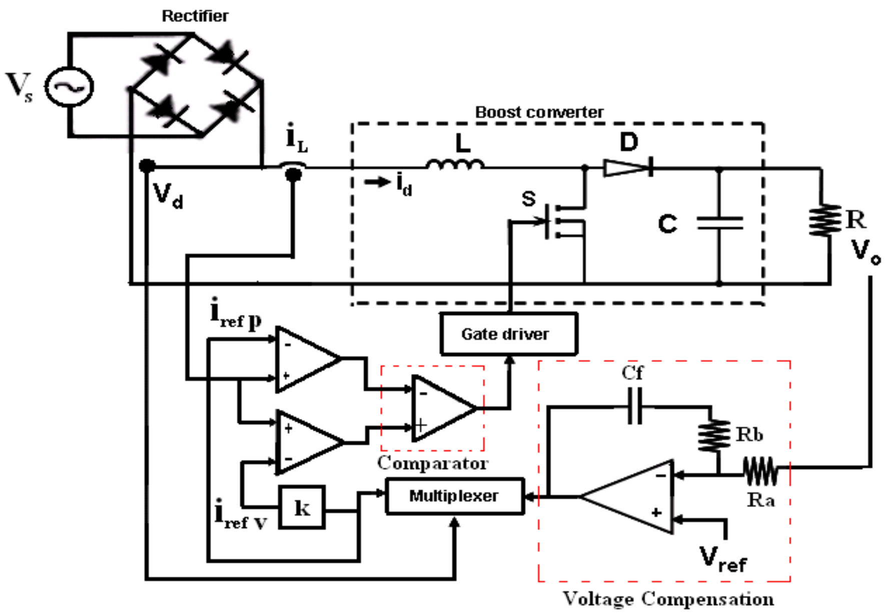


Figure 2. Hysteresis with VSF control for single-phase boost PFC converter.

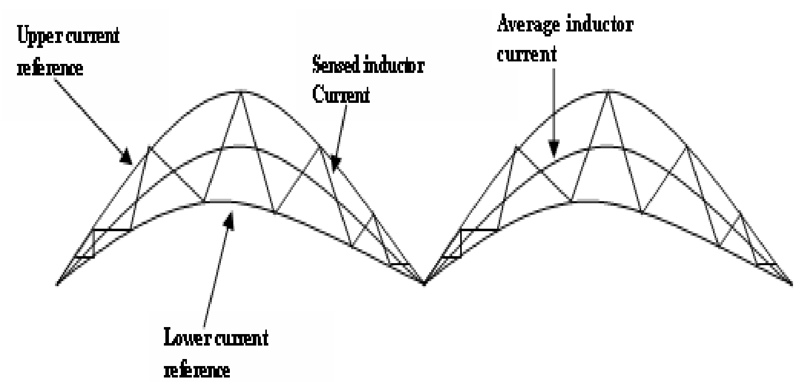


Figure 3. Boost inductor current with hysteresis control.

The control technique is designs so that the inductor current follows the shape of the rectified ac line voltage. To regulate the load, the error amplifier senses the variation between the output voltage and the fixed dc reference. This error voltage is multiplied with the sensed rectifier line voltage to control the inductor current amplitude. The advantages of the control are does operate over a large input range, no need of compensation ramp, converting a voltage source into a fast-acting current source, the inductor is easy to design, operate high switching frequency, and low distorted input current waveforms with fixed load. The disadvantages of the control are the frequency is constantly changing, the circuit likes fixed load that do not vary, the frequency goes very high for light load high line, filter is larger than standard SMPS filter, and current peaks are higher than continuous duty mode.

3. Research Method

The hysteresis design requirements maximum output wattage, lowest frequency desired, lowest AC line voltage, highest AC line voltage, and desired DC output voltage.

3.1 Design of Duty Cycle and Transistor turn-On

$$(V_p \, Sin \;\; \omega \, t) \, t_{on} = (V_o - V_p \, Sin \;\; \omega \, t) \, t_{off} \tag{1}$$

Therefore,

$$\therefore \; d(t) = 1 - \frac{V_p \, Sin \;\; \omega \, t}{V_o} \tag{2}$$

where,

$$\omega = 2\pi f_{line} = 100\pi \;\; , \;\; \Delta = \frac{\delta}{I_M} \times 100\%$$

$$t_{on} = \frac{\delta L_F}{V_P - \omega L_p I_P Cot\omega t}$$

3.2 Inductor Design

The selection of inductor and the capacitor in the Boost topology plays a major role in the output response. The inductor (L) is given in eqn (3),

$$L = \frac{\Delta t_{on} \times V^2{}_{rms\,\min} \times \eta}{2 \times W} \tag{3}$$

$$R = \frac{V_{dcOutput}}{\sqrt{2} \times V_{rms\,\min}} - 1 \tag{4}$$

where,

$$\Delta t_{on} = \frac{R}{f_s (1 + R)} \quad \text{or} \quad \Delta t_{on} = \frac{2 \times L \times W}{\eta \times V^2{}_{rms\,\min}}$$

Where V_{rmsmin} is the source voltage, η is the efficiency of the system; W is output power and Δt_{on} is rate of change of on-time.

3.3 Capacitor Design

The capacitor (C) is given as eqn (5),

$$C = \frac{I_o}{\Delta V_o} \left(\frac{\pi}{\omega} - \frac{2V_p}{\omega V_o} \right) \tag{5}$$

Where ω is the frequency, Vp is the Peak source voltage, I_o is the output current and ΔV_o is the peak to peak ripple output voltage.

3.4 Determination of the objective function

The significant subject of the Hysteresis control PFC method is how to determine the objective function. In this paper, Total Harmonic Distortion (THD) of the input current is chosen as the objective function [6]. The objective of the Hysteresis control PFC algorithm is to achieve a high power factor. The ideal situation is unity power factor. The power factor defines as given in eqn (7).

$$\text{Power Factor} = \frac{V_{rms} I_{rms(1)}}{V_{rms} I_{rms}} Cos\phi \tag{6}$$

Therefore,

$$PowerFacto\ r = \frac{I_1}{I_{rms}} \cos\phi \tag{7}$$

where, $I_{rms} = \sqrt{\frac{1}{2}\left(I^2{}_M + \frac{1}{12}\delta^2 \right)}$

In the rectifier cascaded by a PFC circuit, the displacement factor is one. So if the distortion factor approaches one. Unity power factor is realized. The relation between THD and distortion factor is given in eqn (8) and (9).

$$\text{Total harmonic distortion } THD\ (\%) = 100 \times \sqrt{\frac{1}{k_d{}^2} - 1} \tag{8}$$

where, $k_d = \frac{I_{rms\,1}}{I_{rms}}$

Therefore distortion Factor,

$$Distortion\quad Factor\ (DF) = \frac{1}{\sqrt{1 + (THD)^2}} \tag{9}$$

If the THD of line current is minimum, the distortion factor is maximum and the power factor become maximum too. Zero THD means unity power factor.

4. Simulation Results and Discussion

The switching frequency is (20-40) kHz. This gives the gate pulse waveforms as shown in Figure 4, which controls the boost converter circuit. Simulation is performed by MATLAB/Simulink to verify the proposed control technique. Figure 5 is the input (line) current of the PFC Boost circuit under 4.5kw load (full load) with 155V input voltage. The supply current and voltage waveforms of a single phase circuit are shown in from Figure 6 to 9. It shows that the supply voltage and current are in phase with each other and has a power factor closer to unity.

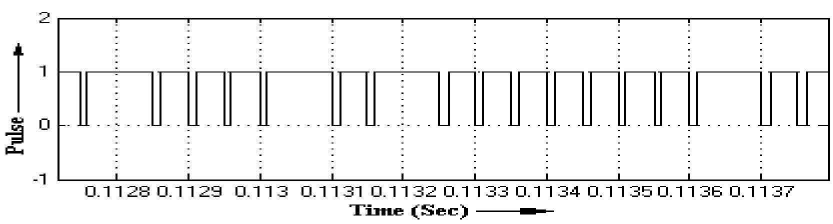


Figure 4. Gate pulses

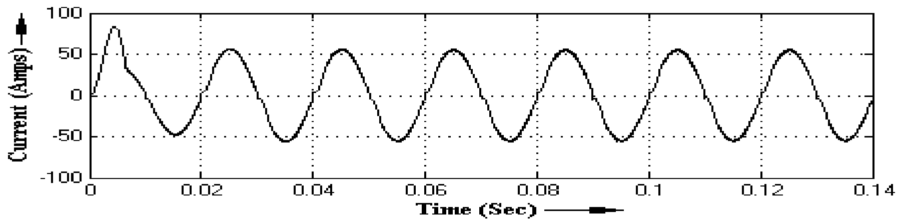


Figure5. Line current waveforms.

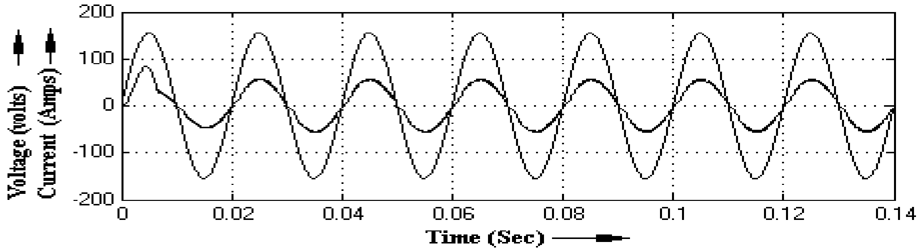


Figure 6. Line Voltage and Line current waveform at line voltage is 155V.

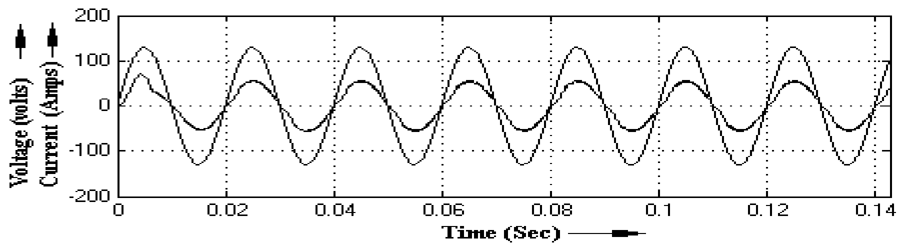


Figure 7. Line Voltage and Line current waveform at line voltage is 130V.

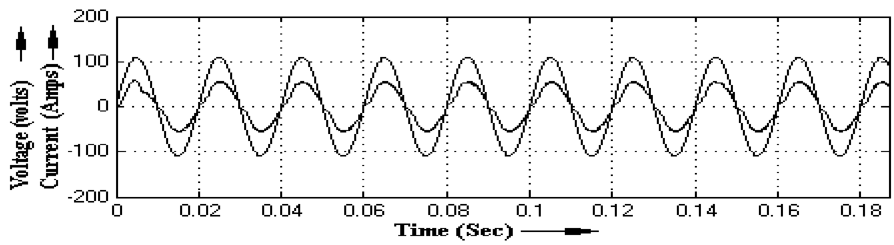


Figure 8. Line Voltage and Line current waveform at line voltage is 110V.

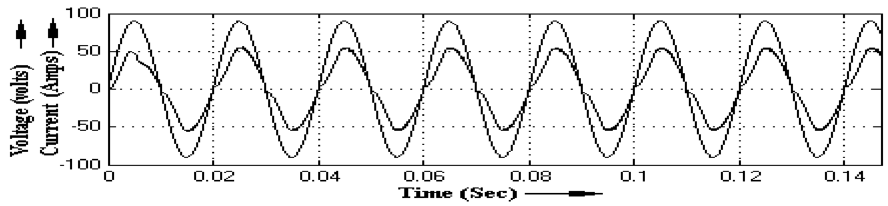


Figure 9. Line Voltage and Line current waveform at line voltage is 90V.

Figure 10 to shows the output voltage of the rectifier circuit. In this paper observed power factor at different input line voltage (90V-155V) as shown in Figure 11. The THD of the current is less than 5% which is shown in the Figure 12. The hysteresis variable switching frequency PFC control strategy can achieve very high power factor. It is shown that, with 90-

155V input voltage, the power factor is under full load is shown in Figure 11. Figure13 shows the line current virus distortion factor it is always closer to unity. Output voltage of boost converter across resistor of 53 ohms having the voltage of 395.8V and is operating at a almost constant d.c. voltage.

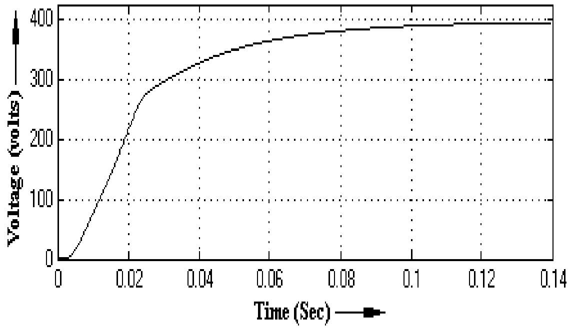


Figure 10. Output voltage waveform.

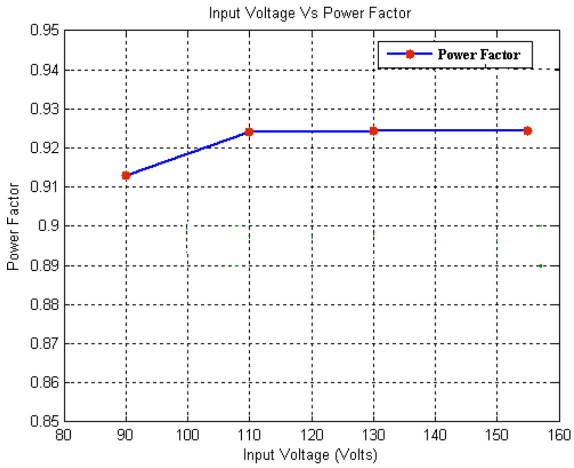


Figure 11. Line Voltage virus Power factor

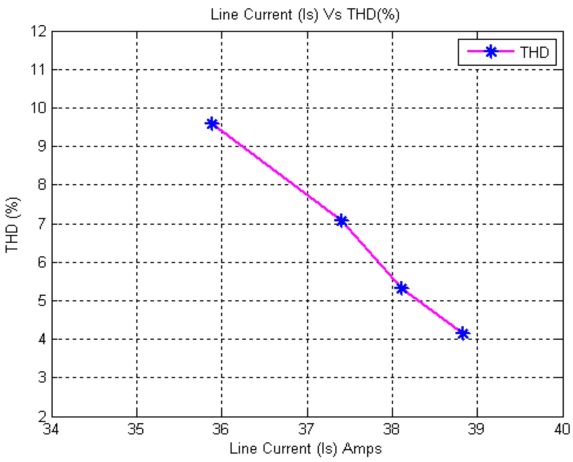


Figure 12. Line current virus Total harmonic distortion (THD %)

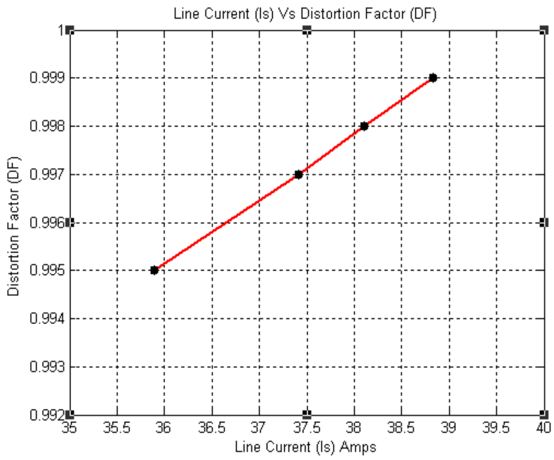


Figure 13. Line current virus Distortion factor (DF)

Table.1. Summary of performance evaluation.

Input voltage (volt)	Power Factor (PF)	Total harmonic distortion (THD %)	Distortion factor (DF)	Output power (watt)	Input power (watt)	Efficiency (%)
90	0.9130	9.60	0.995	3006.6	3230.1	93.0
110	0.9240	7.06	0.997	4638.6	5133.0	90.3
130	0.9243	5.33	0.998	5477.0	5954.0	92.0
155	0.9243	4.14	0.999	5800.0	6045.0	93.1

5. Conclusion

A proposed variable switching frequency (Hysteresis) control for ac-dc converter PFC method based on the Boost topology. The advantage of Hysteresis variable switching frequency technique is no need of ramp compensation, low distortion input current waveform. The disadvantages in the existing PFC control implementation based on conventional PWM control.

This system considered uses a unified overcomes such a drawback by converting a voltage source into a fast-acting current source by using this proposed variable switching frequency (Hysteresis) control technique, all the duty cycles required to achieve closer to unity power factor with the switching frequency of (20 - 40) kHz. The design equations for selecting output capacitance and power factor have been presented. Simulation results shows that the proposal strategy works well and near unity power factor can be achieved over wide input voltage and load current variation range. The THD is well decreased with proposed hysteresis variable switching frequency technique.

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