Pure Sinusoidal Input Voltage Based Bridgeless PFC Converter Using TMS320F2812 Digital Signal Processor

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Abstract

This paper presents a new method to eliminate the harmonics contents of the input current. In conventional Power Factor Converters the input voltage is assumed to be a sinusoidal wave and the converter switching is controlled such that the input current is aligned with the input voltage. Since the input voltage is not always a sinusoidal wave and may include different harmonics the input current aligned with the input voltage will also include the same harmonics of the input voltage. For the purpose of eliminating the current harmonics caused by the input voltage harmonics a sinusoidal wave is generated considering the zero crosses of the input voltage and this wave is taken as the reference to obtain an input current of minimum Total Harmonic Distortion (THD) value. The zero crossing point of the ac input voltage is detected using the digital controller that is implemented with TI DSP of TMS320F2812. The bridgeless converter topology is selected for this investigation to improve efficiency, and the average-current control strategy is adopted to control input line current waveform as well as output DC voltage. The simulations were performed in MATLAB/Simulink program. The simulation results are verified by the results obtained from the experiments.

Keywords: Average Current Mode Control, Power Factor Correction, Bridgeless Converter, Digital Signal Processor

1. Introduction

In most of the power conversion systems, the AC line voltage is first rectified and regulated to obtain a DC bus voltage. The simple diode bridge rectifiers can easily be used with very low cost. PFC Converters are an important area of this study and research in power electronics. These AC and DC converters provide stable DC voltage at the output with high input power factor and low THD. This capability makes PFC converters an extremely attractive choice for power supplies and other AC and DC power conversation applications.

Evaluating the power loss in power semiconductors is an important step in the process of research, development and design of a power electronics circuit topology. To reduce the rectifier bridge conduction loss, different topologies have been developed. Among these topologies, the bridgeless PFC converter doesn't require range switch, shows both the simplicity and high performance [1, 2]. The bridgeless PFC topology is expected to be more efficient than the conventional boost topology because it has less number of semiconductor devices on the current path.

Single switch Continuous Conduction Mode (CCM) PFC is the most widely used topology for the PFC applications because of its simplicity and smaller EMI filter size. Due to the high conduction loss and switching loss, this circuit has a low efficiency at low input line [3].

The average current control mode (ACCM) is the most popular control method because of its high performance and easy to understand [4]. The controller multiplies input voltage signal with the voltage loop output voltage to generate the current reference while the current loop controls the inductor average current to follow the current reference.

In practical applications the ac mains voltage may not be a sinusoidal wave. The distorted ac voltage includes harmonics. Since the PFC circuits adjusts the input current to be in phase with the input ac voltage, the input ac current shape will be similar to that of the ac input voltage and will have harmonics increasing the THD of the input current [5]. The aim of this control purpose is to remove this problem and to decrease the input current THD factor.

The zero crossing point of the ac input voltage is detected using TMS320F2812 Digital Signal Processor that has high speed sampling range and widely using industrial applications.

2. Application of Bridgeless PFC Topology

The Bridgeless PFC converter is shown in Fig. 1. This configuration reduces the number of semiconductor devices in the inductor charging-current path from three to two, lowering conduction loss.

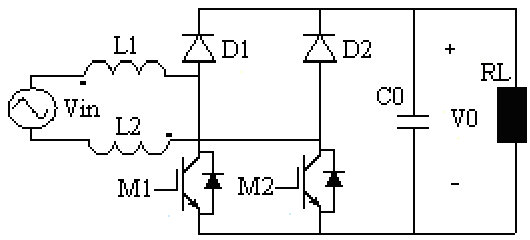

Fig. 1. Bridgeless PFC converter topology

It can be seen from Fig. 1 that the proposed topology essentially comprises two single-phase boost converters without input line frequency diode rectifier. The input current and output voltage are modulated by the switch M_1 in the positive half-period and M_2 in the negative half-period of input voltage respectively, so it can be called bridgeless PFC topology. In addition, it has an advantage of high efficiency in contrast with the single-phase boost PFC with rectifier, and its gate drive circuit is simple for common emitter of M_1 and M_2.

The different operation states of the system during positive and negative half periods of input voltage are given as:

During positive half period of input voltage:

State 1: The switches are in on state. The current flows through switch M_1 and M_2 body diode. At the same time, the capacitor discharges and supplies current to the load.

State 2: The switches are in off state and current flows through D_1, the capacitor together with the load, and return to ac mains through the M_2 body diode.

During negative half period of input voltage:

State 1: The switches are in on state. The current flows through switch M_2 and M_1 body diode. At the same time, the capacitor discharges and supplies current to the load.

State 2: The switches are in off state. Current flows through diode D_2, load, and returns to ac mains through M_1 body diode.

The circuits of the system according to the different operations are shown in Fig. 2.

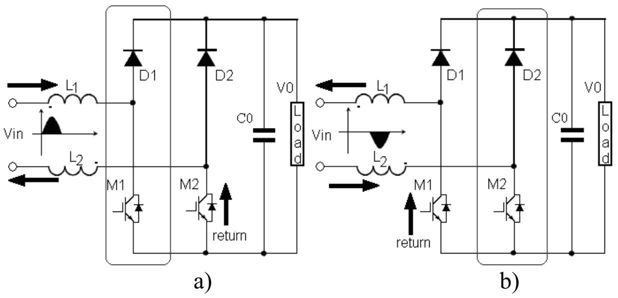

Fig. 2. a) PFC converter in positive half state of input voltage
b) PFC converter in negative half state of input voltage

The equations that are obtained according to the input voltage conditions are given as [6]:

$$V_{in} = V_m \sin(wt) \tag{1}$$

$$V_{in} = L\frac{di_L}{dt} \qquad 0 < t_{on} < DT \tag{2}$$

$$V_{in} - V_0 = L\frac{di_L}{dt} \qquad DT < t_{off} < T \tag{3}$$

The equation that is obtained according to the CCM condition is shown as:

$$V_{in}t_{on} = (V_{in} - V_0)t_{off} \Rightarrow {}^{t_{off}}\!/_{T} = {}^{V_{in}}\!/_{V_0} \tag{4}$$

3. Control Configuration

The control configuration of the system is based on average-current control strategy. There are three sampling signals; input voltage and current, output voltage waveforms. These signals are sampled by LEM transducers and processed by TMS320F2812 digital signal processor. The ACCM is shown in Fig. 3.

TMS320F2812 is a 16-bit fixed-point DSP based on 30MIPS, and has 2 event managers and 16 bit ADC channels. This paper uses 3 ADC channels sampling input voltage (V_{in}), input current (i_L) and output voltage (V_0) and the T1 PWM channel is selected to drive M_1 and M_2.

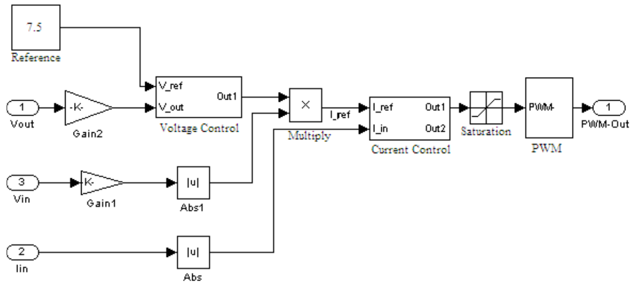

Fig. 3. Block diagram of ACCM

The block diagram of the system is shown in Fig. 4. There are two loops in the program. The inner loop (G_{ca}) responsible for controlling the shape of the inductor current, while the outer loop (G_{vea}) maintains the output voltage at a certain level. Each loop employs a PI controller to perform its task. Pin connections of the TMS320F2812 are shown in Table 1.

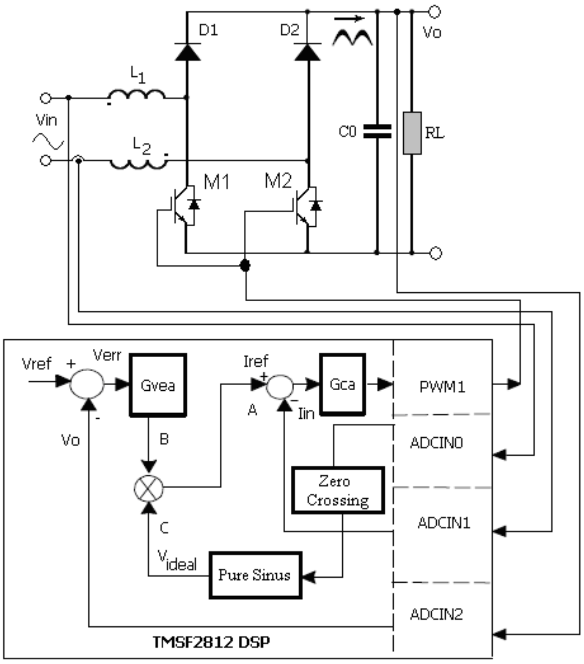

Fig. 4. Block diagram of the control configuration

Table 1. The description of TMS320F2812 pin connections

TMS320F2812 Pins	Description
PWM1	Pulse Width Modulation for M_1 and M_2
ADCIN0	Input voltage sampling pin
ADCIN1	Input current sampling pin
ADCIN2	Output voltage sampling pin

In conventional PFC converters the input voltage is assumed as a sinusoidal wave and the converter control is achieved based on this assumption. This approach can't be a suitable technique for the converters.

In this new control technique zero crossing points of input voltage are determined by the DSP. So, the ideal sine-wave signal can produce by looking these zero crossings points of sampling input voltage. Reference input voltage could be used by controller and generates reference current by it. Using the aimed approach control the THD of the input current is very low with respect to that of input current of the conventional PFCs.

The block diagram of the program for proposed system is shown in Fig. 5.

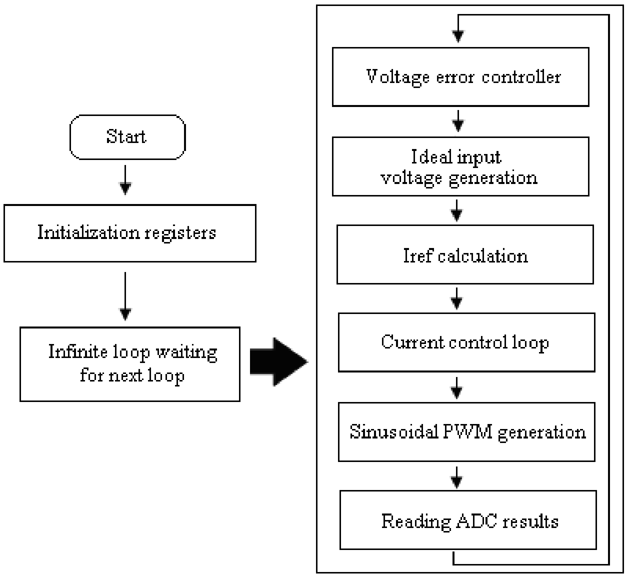

Fig. 5. Block diagram of the program for proposed system.

4. Simulation of The System

The simulation is performed by MATLAB/Simulink program for different cases of operation. The system was simulated using proposed and conventional control methods. Using the proposed approach control the THD of the input current is very low with respect to that of input current of the conventional PFCs. Simulation conditions are follows in Table 2.

Table 2. Simulation parameters

P	600 W
V_0	400 V
V_{in}	220Vrms / 50Hz
Switching frequency - f_s	50 kHz
Inductance value - L_1, L_2	500 µH
Output Capacitor - C_0	500µF
Load - R_0	278Ω

Fig. 6 shows the output voltage, input current and input voltage respectively for the case that the system is free of control. It is shown that the output voltage and input current have harmonics.

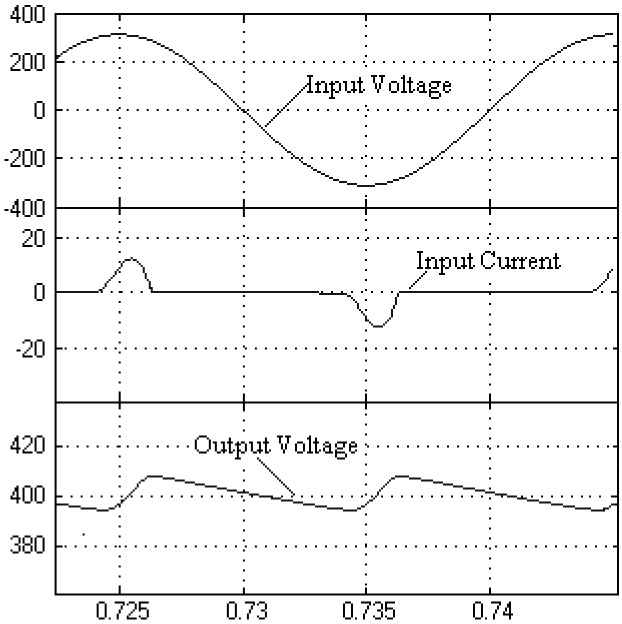

Fig. 6. Input voltage, input current and output voltage waveforms of output voltage control system (V_0=400V_{dc}, V_{in}=220V_{rms}, R_L= 278Ω)

In Fig. 7, the input current THD value is about 141.84%. With this value, it is seen that output voltage control system has a worst case of THD of input current.

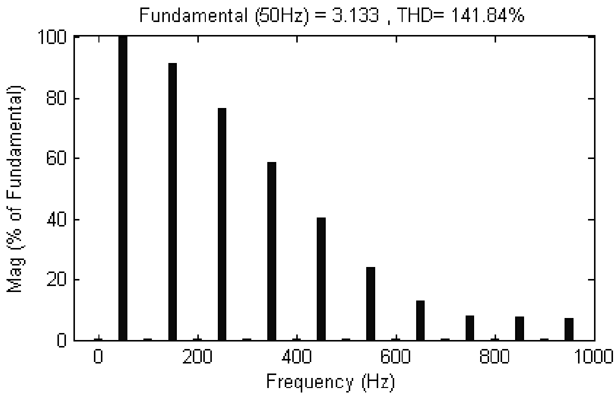

Fig. 7. THD of Input current of output voltage control system

Fig. 8 shows the input voltage, input current and output voltage respectively for the case where the system is conventional control. It is shown that the input current has harmonics. In Fig. 9, the input current THD value is about 10.26%. With this value, it is seen that conventional controlled has a high THD of input current.

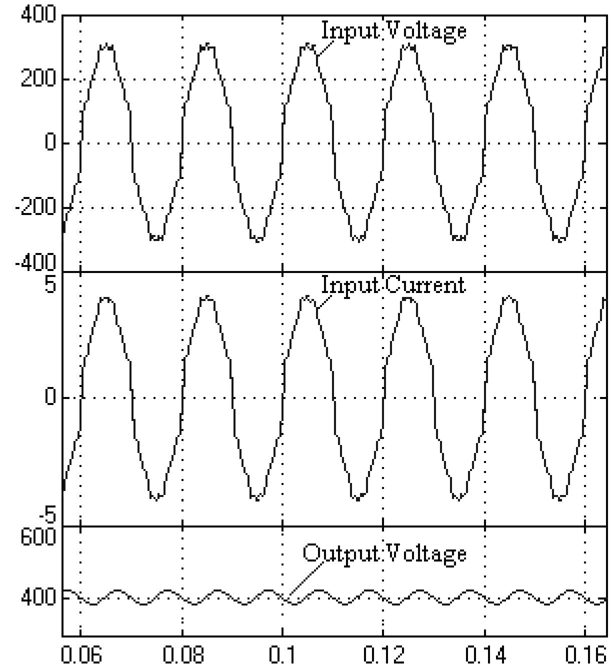

Fig. 8. Conventional Bridgeless PFC converter signals (V_0=400V_{dc}, V_{in}=220V_{rms}, R_L= 278Ω, P=600W)

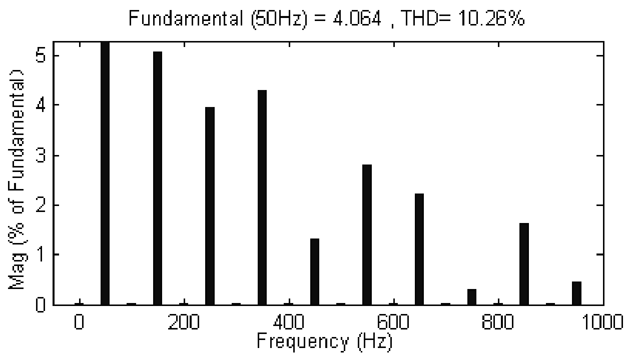

Fig. 9. THD of Input current of conventional system

. In Fig. 10, the input current THD value is about 2.22%. It is shown that the input current has no harmonics. Fig. 11 shows the input voltage, input current and output voltage respectively for the case where the system is controlled.

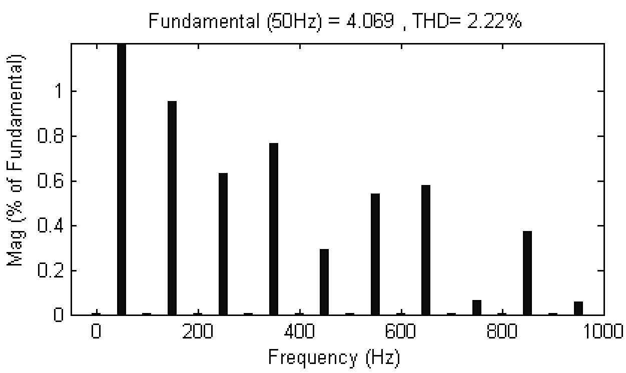

Fig. 10. THD of Input current of proposed system

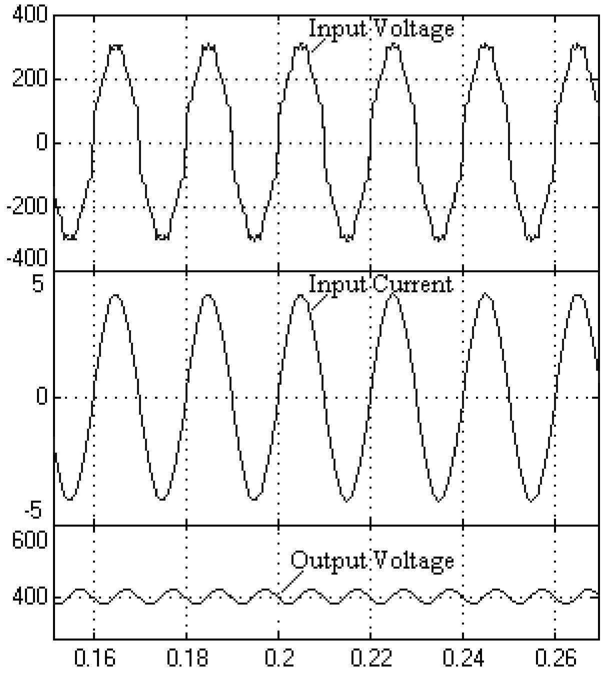

Fig. 11. Proposed Control of Bridgeless PFC converter (V_0=400V_{dc}, V_{in}=220V_{rms}, R_L= 278Ω, P=600W)

5. Experimental Results

The experiment results of proposed Bridgeless PFC Converter for the ACCM technique are described. The implementation is made by DSP TMS320F2812 devices and the control algorithm is implemented to this microprocessor. The LEM LTS25-NP current transducer has been used to sense the input current and to sense the voltages; the LEM LV25-P voltage transducers have been used. The prototype circuit is shown in Fig. 12. The circuit parameters are shown in Table 3.

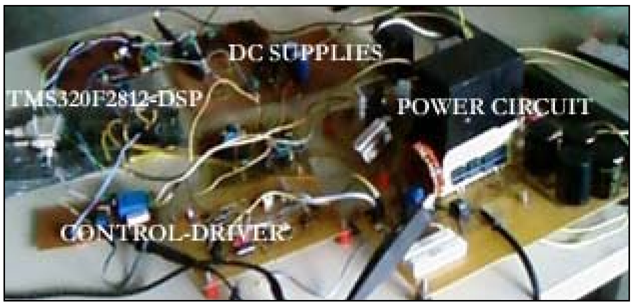

Fig. 12. Experimental Set of Bridgeless PFC circuit

Table 3. Circuit parameters

Inductance value - L_1, L_2	500 μH
Switching frequency - f_s	50 kHz
MOSFETs - M_1 and M_2	IXGH24N60CD1
Fast diodes - D_1 and D_2	IXYSDSEI6012A
Output Capacitor - C_0	500μF

Experimental values are: V_0=400V_{dc}, V_{in}=220V_{rms}, R_L= 278Ω. In figures output voltage is scaled %5 and input voltage is scaled %7 by voltage division. Using Bridgeless PFC converter prototype, Fig. 13 shows the input voltage, input current and output voltage for the case that the system is controlled only output voltage control. According to this result, the input current is included harmonics without proposed control technique.

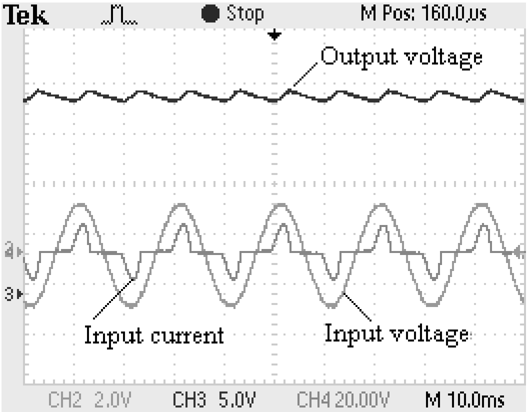

Fig. 13. Experimental results of output voltage control

Fig. 14 gives that a) Input voltage, input current and power factor and power values of only voltage control process without proposed control, b) Total harmonic distortion of Input current for only voltage control process without proposed control. c) Input voltage, input current and power factor and power values of proposed control process, d) Total harmonic distortion of Input current for proposed control process.

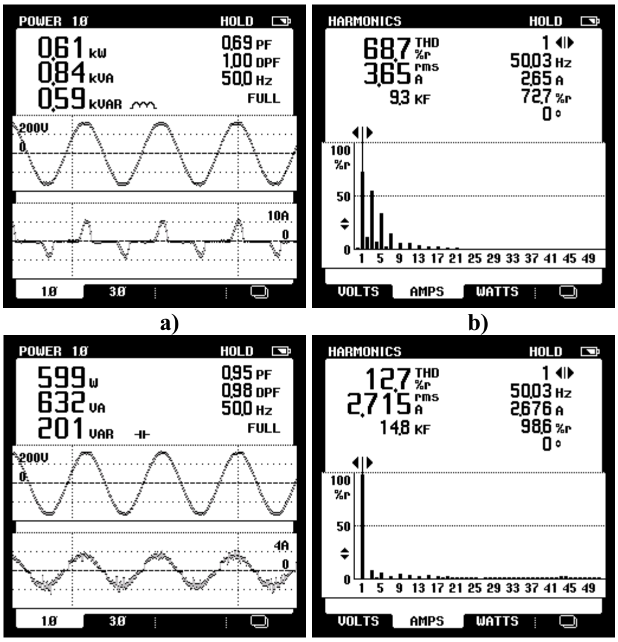

Fig. 14. Analysis of input current signal of converter

Fig. 15 shows the input voltage, input current and output voltage for the case that the system is proposed control of Bridgeless PFC converter prototype. According to these results, the input current harmonics that is reflected from input voltage source has eliminated by proposed control technique.

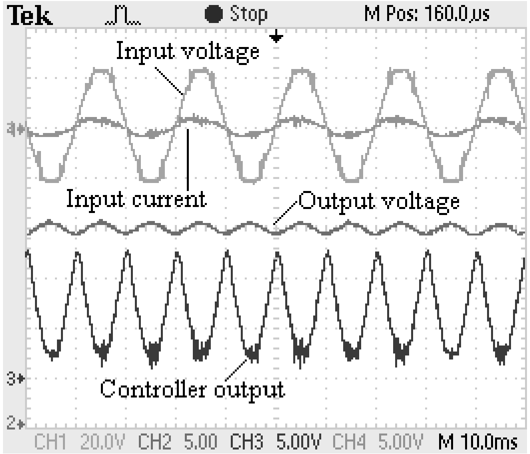

Fig. 15. Experimental results of proposed control technique

6. Acknowledgement

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7. Conclusions

This study presents the analysis and design of an experimental study on the single-phase Bridgeless PFC converter that is controlled by DSP TMS320F2812 in proposed control technique. Eliminating the current harmonics caused by the input voltage harmonics a sinusoidal wave is generated considering the zero crossing of the input voltage and this wave is taken as the reference to obtain an input current of minimum THD value. The bridgeless converter topology is selected to improve efficiency, and the average-current control strategy is adopted to control input line current waveform as well as output DC voltage. The performance of control approach and experimental prototype studies are successfully validated.

8. References

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