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Current total harmonic reduction technique on three-level single phase transformerless photovoltaic inverter using PSpice

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ABSTRACT

This paper presents simulation of three-level single phase transformerless photovoltaic inverter (TPVI). Proposed technique of the simulation is created in PSpice software. The simulation is constructed by two voltage controlled switches, ETABLE and EVALUE block diagram. The voltage controlled switches produce two pulse waves with difference time delay which influence maximum voltage angle and current total harmonic distortion (CTHD). These two voltage pulse waves are changed become three-level AC waveform by ETABLE block with magnitude of 1 V and increased by EVALUE block which following value of photovoltaic array voltage. The output of EVALUE block is connected to AC loads. Resistive load of 30 W lamp and inductive load of 20 W water pump are applied to the TPVI. The result shows that maximum voltage angle which is varied from 20^0 to 180^0 influences the CTHD, the lowest CTHD of 11.75% is obtained when the maximum voltage angle is 125^0.

Keywords: *Photovoltaic inverter, transformerless, AC waveform, solar irradiance, temperature.*

INTRODUCTION

The direct current (DC) electrical energy of PV module can be converted to AC electrical energy using inverter. The 1.5 kW inverter using full bridge topology is designed and tested by (1). It gave an excellent result for the high power PV module application. An alternative approach of inverter is proposed by (2) to replace the conventional method with the use of microcontroller. The use of the microcontroller brings the flexibility to change the real-time control algorithms without further changes in hardware. It is also low cost and has small size of control circuit for the single phase full bridge inverter.

In grid or off grid connected installation, the inverter input power is determined by the solar irradiance on the PV module, that is, both the efficiency and the electricity supply quality depend on the inverter work point (obviously this depends on the solar irradiance incident on the surface of the PV module) (3).

This paper presents a new topology of three-level transformerless PV inverter. It consists of three main circuits; they are a pulse driver circuit, a full bridge inverter circuit and a power factor correction circuit that have functions as production of pulse waves, to develop alternating current (AC) waveform and to stable voltage of PV array. The three main circuits were modeled using PSpice software. Blocks of voltage controlled switch, ETABLE and EVALUE represented the pulse driver, power factor correction and full bridge circuit, respectively. Maximum voltage angle of AC three level waveform can be adjusted by the voltage controlled switch, and therefore CTHD of the same loads can be optimized.

RESEARCH METHODOLOGY

Proposed topology

Proposed technique to reduce current total harmonic distortion (CTHD) on three-level single phase transformerless PV inverter using PSPice by following Figure 1.

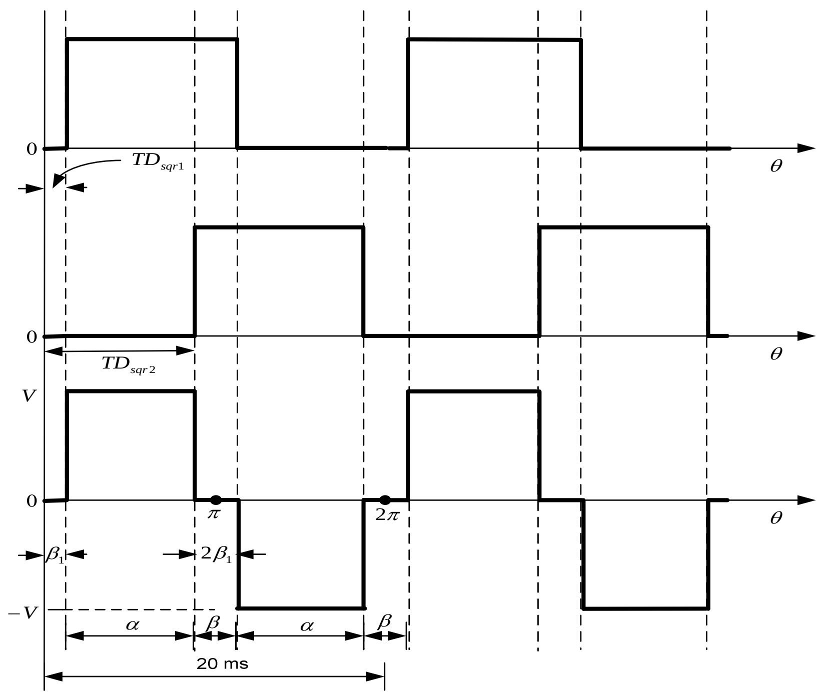


Figure 1: Three-level Waveform on Single Phase Transformerless PV Inverter

From Figure 1, time delay of the first pulse, TD_{sqr1} and the second pulse, TD_{sqr2} are given by

$$TD_{sqr1} = \frac{\beta_1 / 360}{f} \tag{4}$$

$$TD_{sqr2} = \frac{1}{2f} - \frac{\beta_1 / 360}{f} \tag{5}$$

For $f = 50$ Hz, relationship between α, β and β_1 is derived below.

$$\begin{aligned}
\alpha &= TD_{sqr2} - TD_{sqr1} \\
&= \frac{1}{2f} - \frac{\beta_1 / 360}{f} - \frac{\beta_1 / 360}{f} \\
&= \frac{1}{2x50} - \frac{\beta_1}{360x50} - \frac{\beta_1}{360x50} \\
&= \frac{1}{100} - \frac{\beta_1}{18000} - \frac{\beta_1}{18000} \\
&= \frac{1}{100} - \frac{2\beta_1}{18000}
\end{aligned}$$

$$\alpha = \frac{180 - 2\beta_1}{18000}$$

$$\begin{aligned}
180 - 2\beta_1 &= 18000\alpha \\
2\beta_1 &= 180 - 18000\alpha \\
\beta_1 &= 90 - 9000\alpha
\end{aligned}$$

$$\beta_1 = 90(1 - 100\alpha) \tag{6}$$

$$\beta = 2\beta_1 \tag{7}$$

In eqn. (6), unit of maximum voltage angle, α and zero voltage angle, β are in second and degree, respectively. Eqn. (6) and (7) show that if the maximum voltage angle, α increase, therefore the zero voltage angle will decrease. Reduction technique of the CTHD on three-level single phase transformerless PV inverter is varying value of α, β and β_1 as shown in Table 1. Optimum values of α, β and β_1 are decided when the CTHD is the lowest.

Table 1: Zero and Maximum Voltage Angle, β, α and β_1

No	α		β		β_1	
	(degree)	**(ms)**	**(degree)**	**(ms)**	**(degree)**	**(ms)**
1.	20	1.12	15 8.57	8.88	79.92	4.48
2.	40	2.24	138.57	7.76	69.84	3.91
3.	60	3.36	118.57	6.64	59.76	3.35
4.	80	4.48	98.57	5.52	49.68	2.78
5.	100	5.60	78.57	4.40	39.60	2.22
6.	120	6.72	58.57	3.28	29.52	1.65
7.	125	7.00	53.57	3.00	27.00	1.51
8.	130	7.28	48.57	2.72	24.48	1.37
9.	133	7.448	45.57	2.552	22.97	1.29
10.	134	7.50	44.64	2.50	22.5	1.26
11.	135	7.56	43.57	2.44	21.96	1.23
12.	140	7.84	38.57	2.16	19.44	1.09
13.	160	8.96	18.57	1.04	9.36	0.52
14.	180	10.00	0	0	0	0

Reduction technique of current total harmonic distortion (CTHD) on three-level single phase transformerless PV inverter by following eqn. (4) to (7) and implemented in PSPice [(4)] as shown in Figure 2 and explained below.

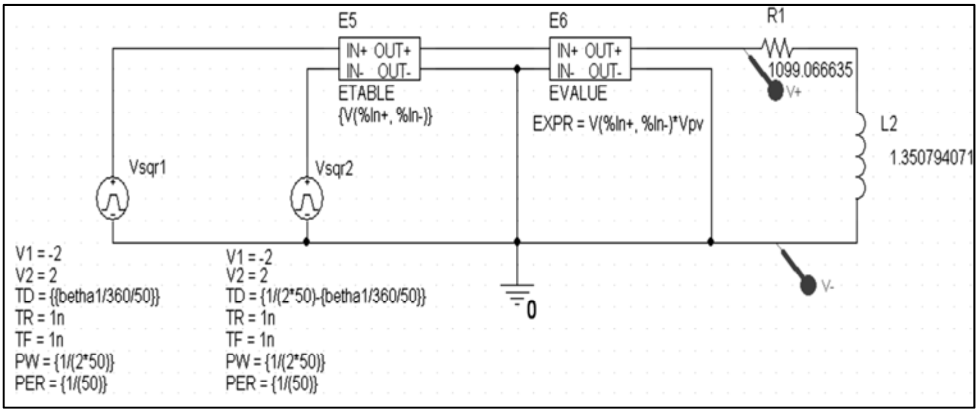


Figure 2: Block of CTHD Reduction Technique of Three-Level Single Phase Transformerless PV Inverter

a. The first and second voltage pulse waves are created by two blocks of voltage controlled switch (V_{sqr1} and V_{sqr2}) with time delay as given in eqn. (4) and (5) that will effect on zero voltage angle, β and CTHD of the three-level transformerless PV inverter.
b. These two voltage pulse waves are change become three-level AC waveform by ETABLE block with magnitude of 1 V as shown in Figure 3.

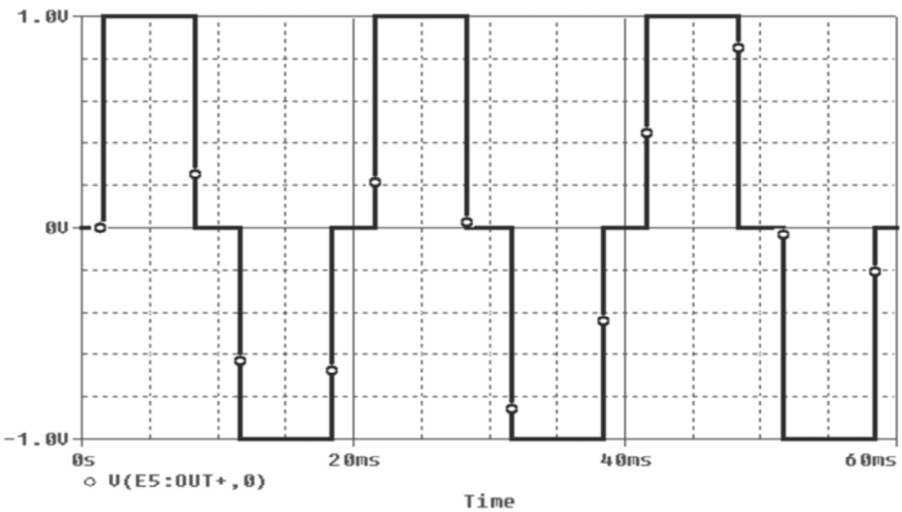
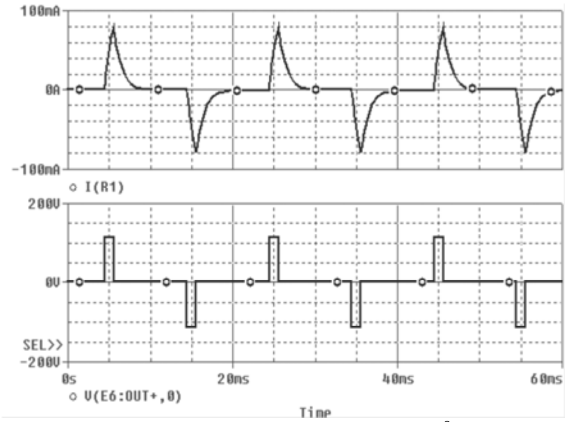


Figure 3: Three-level AC Waveform of ETABLE Block Output

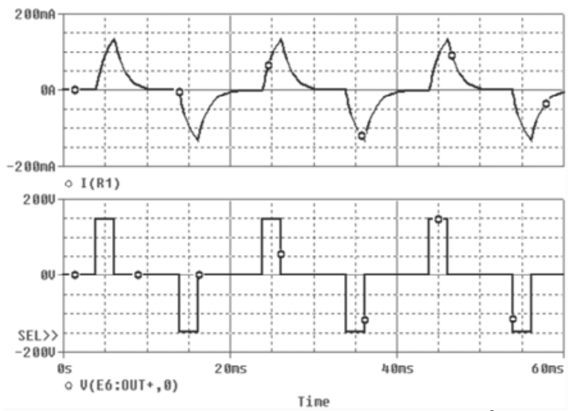
c. The voltage magnitude of three-level AC waveform of ETABLE block output is increased by EVALUE block that following value of PV array voltage (Vpv). The output of EVALUE block is connected to AC loads.
d. View simulation result and view simulation output file are used to observe

RESULTS AND DISCUSSION

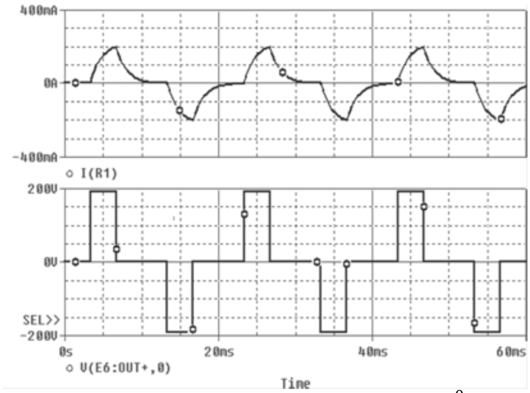
Maximum voltage angle, α influences the rms voltage, current and load impedance. Change of rms voltage, current and load impedance influences the current total harmonic distortion (CTHD) (Hart, 2011). Voltage and current waveforms for varies maximum voltage angle, α are shown in Figure 5.



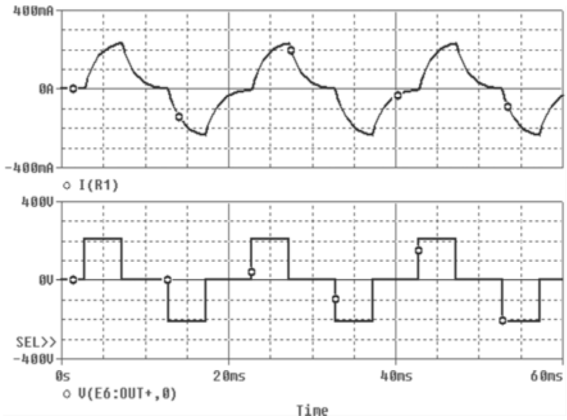
Maximum voltage angle at 20^0



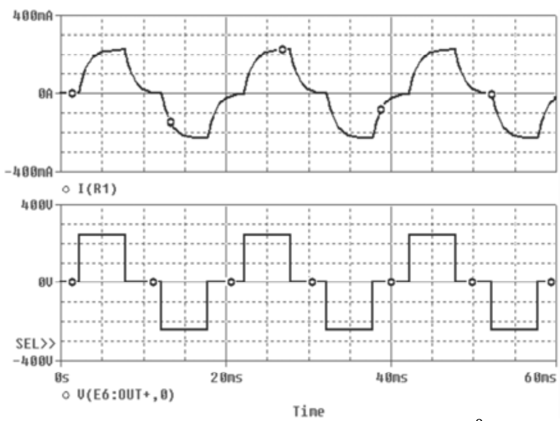
(a) Maximum voltage angle at 40^0



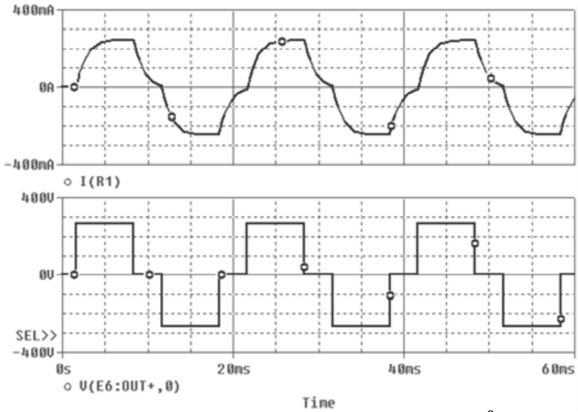
(b) Maximum voltage angle at 60^0



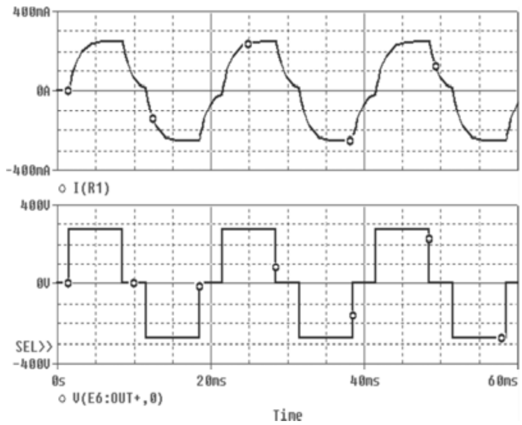
(c) Maximum voltage angle at 80^0



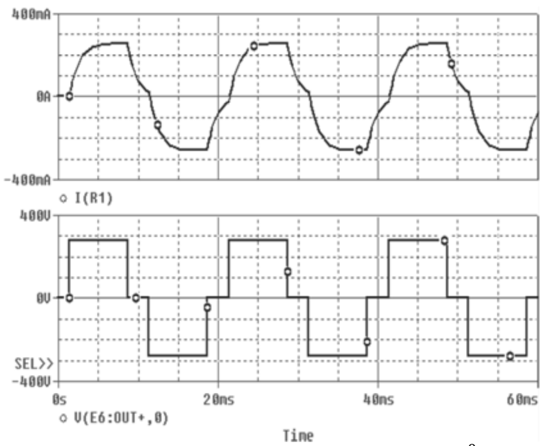
(d) Maximum voltage angle at 100^0



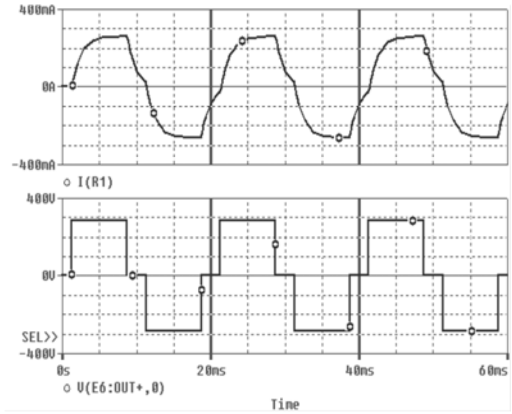
(e) Maximum voltage angle at 120^0



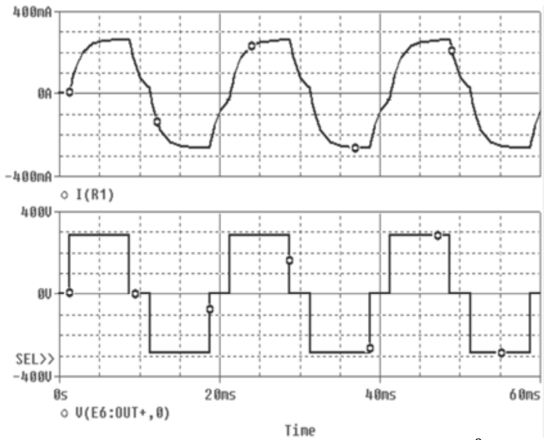
(f) Maximum voltage angle at 125^0



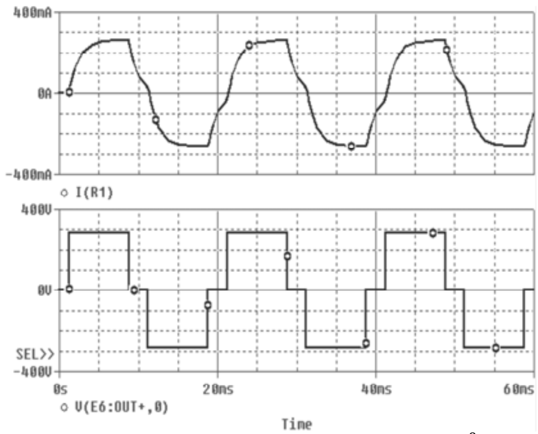
(g) Maximum voltage angle at 130^0



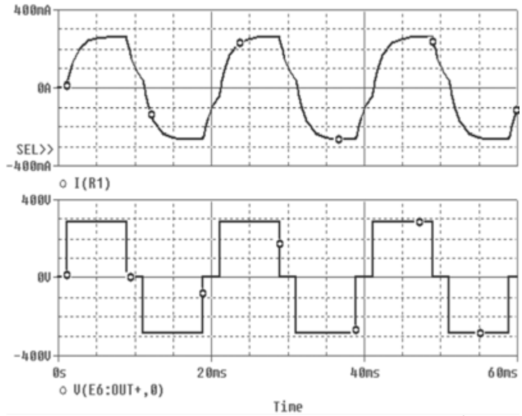
(h) Maximum voltage angle at 133^0



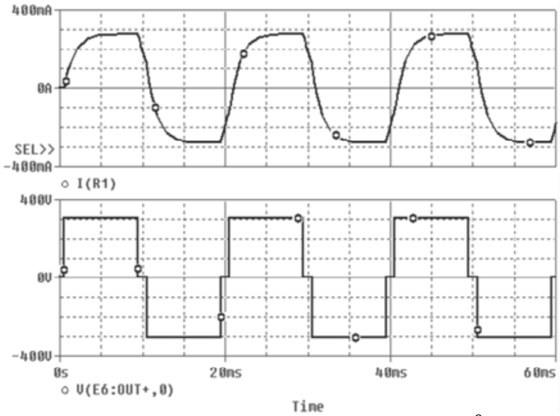
(i) Maximum voltage angle at 134^0



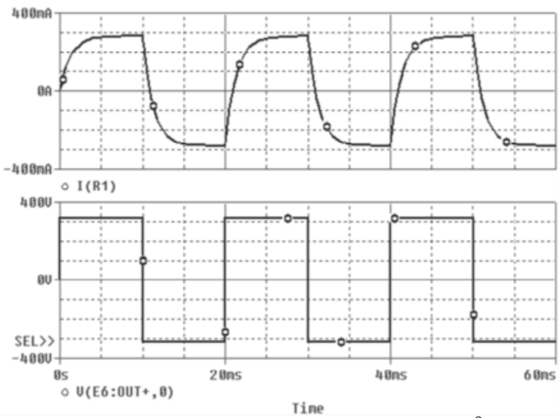
(j) Maximum voltage angle at 135^0



(k) Maximum voltage angle at 140^0



(l) Maximum voltage angle at 160^0



(m) Maximum voltage angle at 180^0

Figure 4: AC Voltage and Current Waveform of Three Level Single Phase Transformerless PV Inverter for Varies Maximum Voltage Angle, α

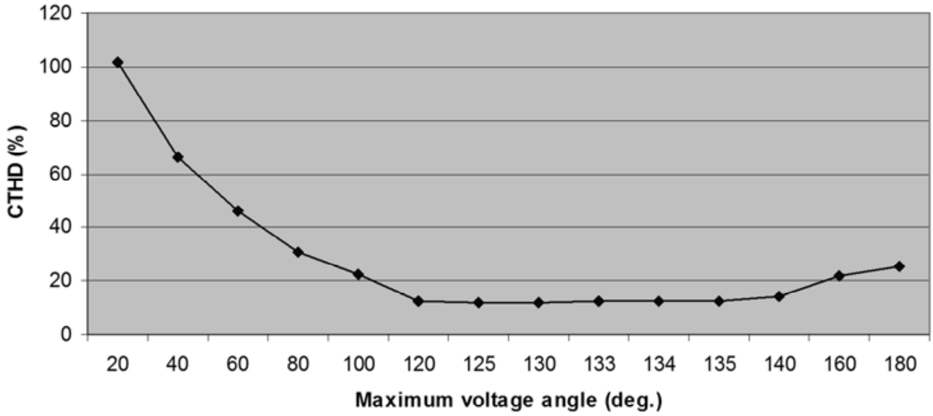


Figure 5: CTHD of Three Level Single Phase Transformerless PV Inverter

Figure 5 shows CTHD simulation of transformerless PV inverter. Maximum voltage angle effects on the CTHD. In the simulation, the maximum voltage angle is varied from 20^0 to 180^0. The lowest CTHD of 11.75% was obtained when the maximum voltage angle is 125^0.

CONCLUSIONS

1. The tranformerless PV inverter can be simulated using blocks of voltage controlled switch, ETABLE and EVALUE of the PSpice software represented the pulse driver, power factor correction and full bridge circuit, respectively.
2. The maximum voltage angle of AC three-level wave can be adjusted using block of voltage controlled switch, it will influence the CTHD.
3. In the simulation, the maximum voltage angle is varied from 20^0 to 180^0. The lowest CTHD of 11.75% was obtained when the maximum voltage angle is 125^0.

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