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Analysis of Cascaded H-Bridge Multilevel Inverter for Three-Phase Induction Motor Drive

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ABSTRACT- The last ten years have seen a rise in the usage of multilayer inverters. Because they can produce waveforms with a greater harmonic spectrum and reliable output. Several high voltages and high-power applications are suitable for these new inverters. A multilayer converter not only produce high power ratings, but it also saves time and money and enhances the system performance in terms of harmonics, dv/dt strains, and pressures on the motor bearings. Owing to its flexibility and modularity, the possible topology for a power application is the cascaded H-bridge multilevel inverter (CMI) with separated DC sources. This study investigates a cascade H bridge multilevel inverter, such as a Three, Five, Seven, Nine and Eleven level inverter in order to drive a three phase AC induction motor. A Level shifted Pulse Width Modulation (LSPWM) technique was applied for the CHBMLI. Specific emphasis is given to aspects like modulation and total harmonic distortion that are preferable or necessary for multi-level converters. For both intellectual and scientific considerations, investigating sine triangle carrier pulse width modulation is deemed to be the most auspicious approach. Analysis of the many performance parameters, including load torque, motor speed, and efficiency, an extensive survey is conducted. MATLAB / Simulink is built into the entire system, and simulation results are developed. The purpose of this research is to demonstrate the performance of 9-level and 11-level fed induction motor driving results for Electric Vehicle applications. CHBMLI fed motor drive is better suitable for Induction Motor Drives.

Keywords: Induction motor drive, THD, CHBMLI, Multi Carrier PWM.

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1. INTRODUCTION

A voltage or current with zero or Vdc is produced by voltage source inverters. They are referred to as two-level inverter [1]. High switching frequencies and various types of pulse width modulation methods are required to produce an output voltage or current waveforms with low ripple [2]. However, there are specific constraints on how frequently these two-level converters can operate in moderate voltage and higher power applications primarily by switching and device rating limitations that result in losses [3].

Furthermore, it is important to use semiconductor switching devices in a way that prevents issues with their combinations of series and parallel, which are required to achieve the capability to handle high current and high voltage [4].

In the power industry, multilevel inverters have sparked a lot of attention. They present a novel variety of characteristics which are ideal for reactive power correction [12][13]. Because of how the structure regulates device voltage stress, Using the multilayer structure, a high-power, high-voltage converter might be simpler to build.

By boosting the inverter's voltage levels, the power rating can be raised without needing higher ratings for certain devices [5]. Due to their special design, multilevel voltage source converters do not require a transformer or other series connected synchronized switching devices to achieve voltages at high level with a smaller number of harmonics [18][19]. The output voltage harmonic component appears to alter in shape as the number of voltage levels rises. Nowadays, multilevel converters are a good solution for power applications [20], since they can achieve high power using medium power semiconductors technology [8][11]. Multilevel inverter (MLI) efficiency increases, when low switching frequency control is used [21].

The following are the most appealing aspects of multilayer inverters:

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1. They can provide output voltages with a reduced dv/dt ratio and extremely low distortion.
2. They draw very low-distortion input current.
3. The stress on the motor bearings is decreased since they produce a reduced common mode (CM) voltage. It is also possible to prevent CM voltages by using sophisticated modulation techniques.
4. They are capable of operating at a reduced switching frequency.

Applications for the multilayer inverter range from low power to high power, including power conditioning devices, motor drives and traditional and renewable energy generation and distribution [7][19]. Out of the three topologies, the cascaded H-Bridge multilevel inverter has the best prospective and most reliable as well as getting the best fault tolerance [14].

2. CASCADED H-BRIDGE MULTILEVEL INVERTER

In multilayer converter topologies, three voltage levels are considered the minimum. Bidirectional switches on the multilevel VSC able it to operate in industrial applications in both rectifier and inverter modes. There have been three main multilevel converter topologies employed: converters for cascading H bridge MLI with independent DC sources, diode clamped MLI and flying capacitors MLI. The dc link voltage Vdc is obtained in the multilayer Voltage source Inverter from any equipment that can produce a reliable dc source. The inverter providing some nodes has an energy tank made up of series linked capacitors as shown in *figure 1*.

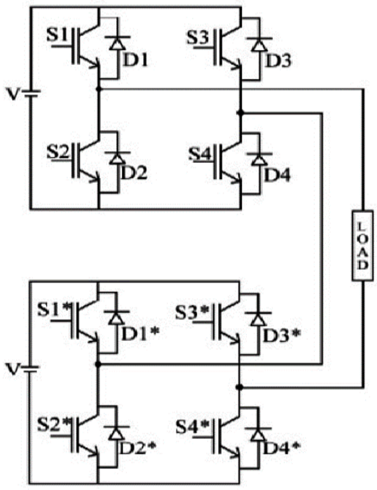

Figure 1. Five-level cascaded inverter with a single-phase leg

It can be connected to a multilayer inverter. Initially, any voltage sources of the same value will be assumed to be series linked capacitors is the capacitor voltage. Vc = Vdc/(n-1), wherever n specifies no of levels. The equation m=2N+1, where about 'N' denotes the no. of sources in DC and 'm' the no. of levels is used to express the output voltage levels. Essentially, the three identical phase leg of a H-bridge converter series-chain create a three-phase CMI design [6], It has the potential to balance the phases of the AC system and may produce various output voltage waveforms. A shared DC link is used in different VSC designs, this capability is not possible. Due to the series power conversion cells used in this architecture, The power and voltage levels are easily adjustable. Diode rectifiers are often fed by the separated secondary windings of three-phase transformers. Each full bridge converter has its own supply of DC linkage which are used to do this. In medium-voltage systems, Phase-shifted transformers have the ability to supply high power quality cells at the utility connection [9].

3. MODELING OF AN INDUCTION MOTOR DRIVE

The three balanced distributed windings of the stator of an induction motor are spaced 120 degrees apart from one another. When electricity passes through such windings, a rotating magnetic field that is produced. Power electronics converter is used in a flexible speed drive system that takes the induction motor dynamic behaviour into account [17]. This machine comprises of an element with in a feedback loop. Because of the stator and rotor windings' coupling effect, studying the machine's dynamic performance is complicated; the coupling coefficient also changes with the position of the rotor [15]. The machine model is thus described as a system of differential equations whose coefficients change with time.

The following assumptions are made in order to derive the machine's dynamic model:

1. Magnetic saturation does not exist.
2. No saliency effects, meaning that the rotor position has no effect on the machine's inductance.
3. The stator winding configuration produces sinusoidal mmf distributions.
4. It is possible that the effects of the stator slots are ignored.
5. There is no distortion in the magnetic circuit.
6. Radially directed magnetic field with constant intensity that spans the air-gap.
7. Minimal hysteresis and eddy current effects.

The motor receives a balanced three-phase supply from the power converter. The two axes theory is used to model the dynamic behaviour of the motor. Time-varying characteristics can be defined by the mutually perpendicular direct and quadrature axes, according to this theory. A stationary model of the machine's d-q dynamic model is used to illustrate it.

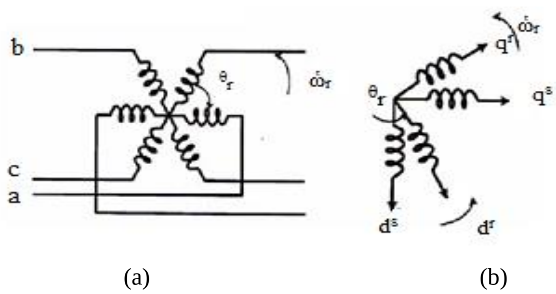

Figure 2. (a) Coupling between the motor's rotor and stator windings (b) Two-phase arrangement

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In a revolving reference frame, the ds and qs axes revolve at an angle to the rotor while being fixed to the stator in a constant reference frame. There are two ways a rotating reference frame can be used: either it is fixed to the rotor or it rotates quickly as shown in Figure 2. When the machine is in a stable state, its variables are represented as dc quantities in a reference frame that rotates synchronously and has a sinusoidal supply.

3.1 Axes Conversion

Transformation from three phase to two phases:
The three phase symmetric machine having 120-degree spacing between the fixed as, bs, and cs axes.

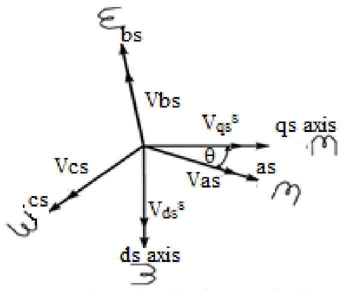

Figure 3. The axis is transformed from a three-phase to two-phase at θ = 0

The voltages are Vas, Vbs and Vcs correspond to the phases as, bs and cs respectively. Let us assume that the voltages along the ds-qs axis are Vdss, Vqss, respectively, and that, as seen in *figure 3*., the ds-qs axes are fixed and oriented at an angle θ.

According to the following equations, Three-phase voltages can be produced from stationary two-phase voltages.

$$V_{as}=V_{qs}^s\cos\theta+V_{ds}^s\sin\theta \quad (1)$$

$$V_{bs}=V_{qs}^s\cos(\theta-120°)+V_{ds}^s\sin(\theta-120°) \quad (2)$$

$$V_{cs}=V_{qs}^s\cos(\theta+120°)+V_{ds}^s\sin(\theta+120°) \quad (3)$$

In matrix form, the phase voltages can be expressed as:

$$\begin{bmatrix} Vas \\ Vbs \\ Vcs \end{bmatrix} = \begin{bmatrix} COS\Theta & Sin\ \Theta & 1 \\ COS(\Theta-120^\circ) & Sin(\Theta-120^\circ) & 1 \\ COS(\Theta+120^\circ) & Sin(\Theta+120^\circ) & 1 \end{bmatrix} \begin{bmatrix} Vqs \\ Vds \\ Vos \end{bmatrix} \quad (4)$$

Vdss and Vqss can be expressed as three phase voltages in matrix form using the inverse transformation:

$$\begin{bmatrix} Vqs \\ Vds \\ Vos \end{bmatrix} = 2/3 \begin{bmatrix} COS\Theta & Cos(\Theta-120^\circ) & Cos(\Theta+120^\circ) \\ Sin\Theta & Sin(\Theta-120^\circ) & Sin(\Theta+120^\circ) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} Vas \\ Vbs \\ Vcs \end{bmatrix} \quad (5)$$

where V0s is the possibility of zero length sequence component, because it is more practical, at θ = 0 and the zero-sequence component are eliminated since the qs and as axes are aligned. Consequently, the conversion relations drop to

$$V_{as}= V_{qs}^s \quad (6)$$

$$V_{bs} = -\frac{1}{2}V_{qs}^s - \frac{\sqrt{3}}{2}V_{ds}^s \quad (7)$$

$$V_{cs} = -\frac{1}{2}V_{qs}^s + \frac{\sqrt{3}}{2}V_{ds}^s \quad (8)$$

$$V_{qs}^s= V_{as} \quad (9)$$

$$V_{ds}^s=\frac{1}{\sqrt{3}}(V_{bs} - V_{cs}) \quad (10)$$

3.1.1. Modeling motor dynamics in a stationary frame

Stanley equations and ωe = 0 in a stationary frame were used to develop the machine model. The equations for the stator circuit are expressed as:

$$V_{qs}^s=R_s i_{qs}^s+\frac{d}{dt}\psi_{qs}^s \quad (11)$$

$$V_{ds}^s = R_s i_{ds}^s+ \frac{d}{dt}\psi_{ds}^s \quad (12)$$

$$0=R_r i_{qr}^s+ \frac{d}{dt}\psi_{qr}^s - \omega_r\psi_{dr}^s \quad (13)$$

$$0 = R_r i_{dr}^s+ \frac{d}{dt}\psi_{dr}^s + \omega_r\psi q \quad (14)$$

Where
ψ_{qs}^s , ψ_{ds}^s = stator flux connections along the quadrature and direct axes

ψ_{qr}^s,ψ_{dr}^s = Rotor flux connections in the q and d axes
Rs, Rr = Resistances in rotor and stator

ω_r = Speed of the rotor and Vdr= Vqr= 0

The air gap flux and rotor mmf interact to create the electromagnetic torque, which is a general vector that can be expressed as

$$Te = \frac{3}{2}\frac{P}{2}(\psi_m) * (I_r) \quad (15)$$

By using appropriate variables, In a stationary frame, the torque equations are expressed as

$$Te = \frac{3}{2}\frac{P}{2}(\psi^s_{dm}I^s_{qr} - \psi^s_{qm}I^s_{dr})$$

$$Te= \frac{3}{2}\frac{P}{2}(\psi^s_{dm}I^s_{qr} - \psi^s_{qm}I^s_{ds})$$

$$Te= \frac{3}{2}\frac{P}{2}(\psi^s_{ds}I^s_{qs} - \psi^s_{qs}I^s_{ds})$$

$$Te= \frac{3}{2}\frac{P}{2}L_m(I^s_{dr}I^s_{qs} - I^s_{qr}I^s_{ds})$$

$$Te = \frac{3}{2}\frac{P}{2}(\psi^s_{dr}I^s_{qr} - \psi^s_{qr}I^s_{dr}) \quad (16)$$

3.2 Operation of Eleven-level and Nine- Level Cascaded H-Bridge Multi Level inverter for Induction Motor Drive

Industry uses three phase induction motors frequently due to their resilience, simplicity of construction, and ease of maintenance. There is a RMF created by three phase currents.

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The drive's supply frequency is directly proportional to the synchronous speed, and three phase currents produce a revolving magnetic flux that rotates at a constant speed [10]. At a steady speed, and the synchronous speed is directly proportional to the drive's supply frequency. As a result, torque is generated as the motor is powered by the force generated by the spinning flux and rotor current. The inverter configuration of an AC induction motor fed by New CHBMLI is designed to connect inverters in single phase to various sources in DC [22][23]. The Cascaded H-Bridge MLI is fed the level shifted multicarrier PWM principle [16][27], which has one modulating signal and a triangular carrier signal. PWM generation is depicted in the *figure 4*. The ratio of the modulating voltage to the maximum carrier voltage (Vtri) determines the pulse pattern or Modulation Index.

$$Ma = \frac{Vcontrol}{V\ tri} \qquad (17)$$

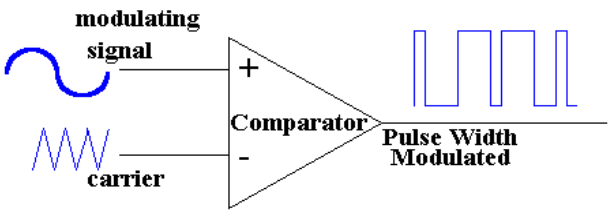

Figure 4. Generation of Pulse width modulation

The fundamental frequency is determined by Voltage control frequency, whereas the amplitude is controlled by the highest value of Voltage control. *Figure 5* and *figure 6* represents AC induction motor driven by a nine-level new cascade inverter along with an eight-carrier pulse generator subsystem and eleven level cascaded inverter fed induction motor [24][25]. Four of them are utilized in the modulating signal's positive duty cycle, and the other four are employed in the negative duty cycle [26].

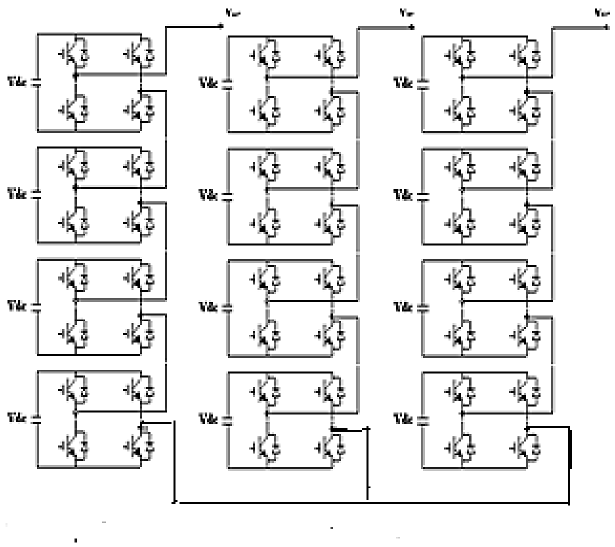

Figure 5. H Bridge multilevel inverter with nine levels of cascade drives a three-phase induction motor.

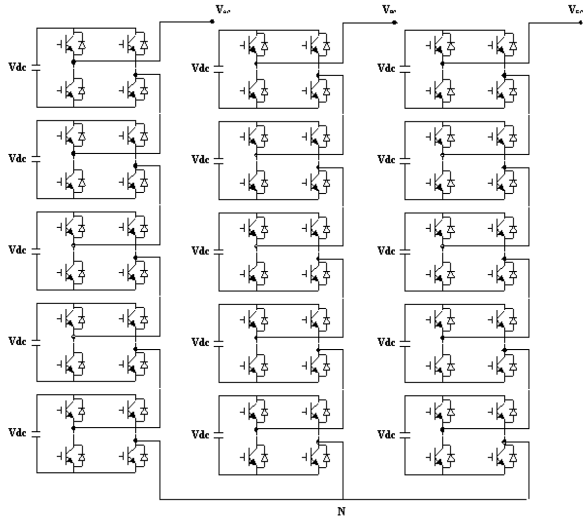

Figure 6. 11 level cascade H Bridge MLI

4. SIMULATION RESULTS AND ANALYSIS

The CHBMLI generates a voltage waveform that is nearly sinusoidal and can be used to drive an induction motor. The Nine-level CHBMLI fed three- phase induction motor and 11-level CHBMLI is enhanced and tested using MATLAB/ Simulink.

The three phase 9-level three phase voltages are shown in *figure 7*. *Figure 8* displays the stator currents about the three phases. Applying the maximum load to the induction motor which is because the motor is treated as a per-unit model displays the fluctuation in torque in Figure 8. The rotor speed increases to 1480 rpm as a result.

Figure 9 illustrates the harmonic spectrum of phase voltage using FFT analysis. The voltage is 400 V, and the THD for voltage is 16.60 percent, with a modulation index (MI) of1.0.

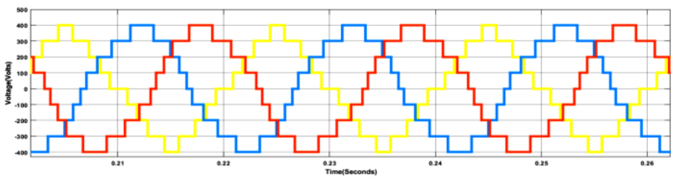

Figure 7. Nine level CHB-MLI three-phase voltages provide power to AC induction motor

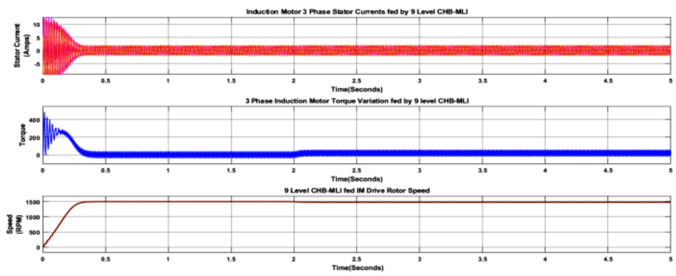

Figure 8. Stator currents, Torque, Rotor Speed for a three phase AC induction motor are supplied by nine level New CHBMLI.

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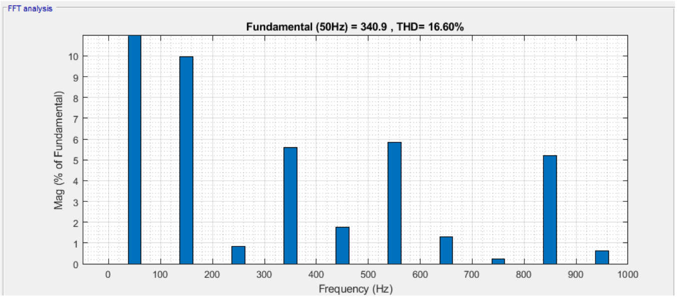

Figure 9. A nine-level new cascaded H-Bridge inverter phase voltage harmonic spectrum at modulation index = 1.0

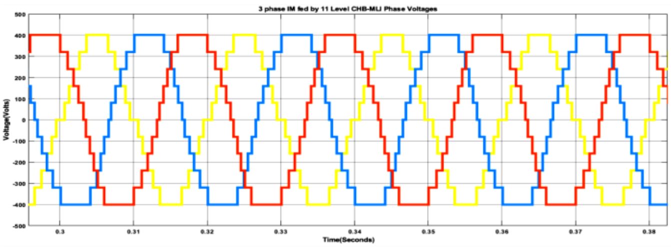

Figure 10. Eleven-level CHB-MLI 3-phase voltages supply power to a twelve-phase induction motor

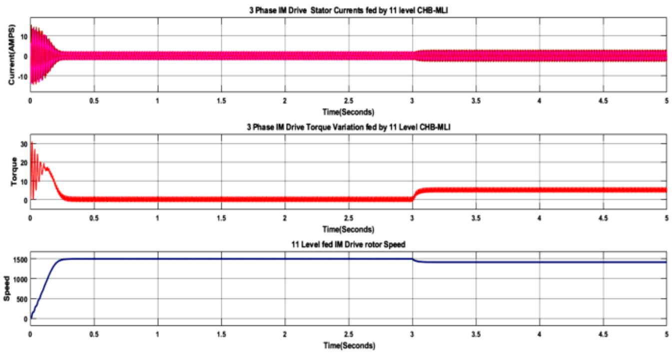

Figure 11. Stator currents, Torque Variations, and Rotor Speed of a 11-level CHBMLI IM drive

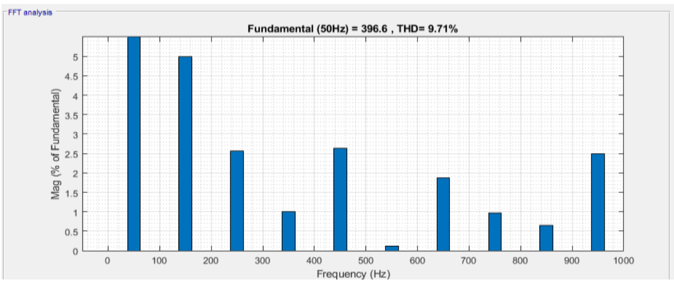

Figure 12. At modulation index = 1.0, Harmonic spectrum of an Eleven level new cascaded inverter phase voltage

The voltage for a three phase AC induction motor driven by eleven level New CHBMLI phase voltages and having a modulation index of 1.0 is displayed in *figure 10*. *Figure 11* depicts three phase stator currents and torque variation. When compared to the nine-level CHB-MLI, the torque ripples are minimized and settle at 1490 rpm, as seen in *figure 11*. The phase voltage harmonic spectrum, with a 400-volt fundamental voltage and a 9.71 percent THD at modulation index 1.0, is displayed in *figure 12*.

4.1 Drive Performance Analysis

The driving system functioning is examined from a variety of perspectives. The simulation results were compiled and shown in graphs and tables. *Table 1* and *table 2* indicate total harmonic distortion for different modulation index.

Table 1. Modulation index for a nine-level new cascaded inverter driven AC induction motor with respect to its total harmonic distortion

Modulation Index	THD (%)
1	16.60
0.9	16.80
0.8	16.97
0.7	21.31
0.6	24.36
0.5	26.96

Table 2. Eleven level new cascaded H Bridge inverter for Three phase AC induction motor modulation index in relation to THD

Modulation Index	THD (%)
1	9.71
0.9	14.40
0.8	12.97
0.7	21.11
0.6	22.36
0.5	26.98

5. CONCLUSION

Analysing the performance of a multilevel cascaded inverter drives an induction motor for Electric vehicle applications; it is obvious that raising the levels improves drive performance significantly. When the induction motor is provided with 11-level CHB-MLI., the system's efficiency is enhanced to 85.08 percent. The modulation index can be changed to provide the necessary inverter output voltage. Higher order harmonics can be filtered out if needed for a specific application. The cost of the filter will be lower because of the increased sinusoidal output, and hence its size will be reduced. Although the no of switches also boosted, switch rating reduces for the same drive rating, resulting in cost reduces. Performance is much more essential than cost when it comes to high-capacity drives.

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