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Improved THD and Simulation of Quasi Z-Source Inverter Fed Induction Motor drive

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Abstract: The major contributor for renewable energy generations are photo voltaic (PV), wind, fuel cell and biomass. These distributed power generation sources are widely accepted for micro grid applications to fulfill domestic power applications. Induction motor is connected at the output side which acts as a load and efficiently utilizes the power obtained from renewable energy generation. This obtained power is used to run the induction motor (IM) through quasi-Z-source inverter. qZSI provides high boost voltage capability and highly efficient single stage boost conversion. The qZSI employs a unique impedance network that couples the inverter main circuit to the dc source and load. qZSI deliver high efficiency and the input current is continuous, suppress inrush current and avoid shoot through fault in inverter when compared to Z-source inverter. The proposed topology of IM is to reduce input current ripple and delivering better power rating. This paper further addresses detailed simulations and control methods of qZSI used for induction motor. The operating principle of the proposed qZSI based induction motor is described and Mat lab/ Semolina simulation is presented to verify the open loop results and reduction in THD.

Key words: Quasi-Z-Source Inverter (qZSI) · Photo voltaic (PV) · Induction motor (IM)

INTRODUCTION

The rapidly increasing environmental degradation across the globe is posing a major challenge to develop commercially feasible alternative sources of electrical energy generation. Thus, a huge research effort is being conducted worldwide to come up with a solution in developing an environmentally benign and long-term sustainable solution in electric power generation. The major players in renewable energy generation are photovoltaic (PV), wind energy farms, fuel cell and biomass [1]. These distributed power generation sources are widely accepted for micro grid applications. However, the reliability of the micro grid relies upon the interfacing power conversion [2]. Thus this paper focuses on the proposal of a new class of interfacing inverter, the quasi-Z-source inverter (qZSI) for Induction motor applications. Power inverter converts Direct current (DC) to Alternating current (AC). Nowadays Z-Source Inverter (ZSI) has becoming a future trend for power systems. This system involves high frequency switching inverter which consists of Z-Source network, filter circuits and controller. A new topology called Z-source inverters have been developed to overcome the problems of the traditional voltage source and current source inverters wherein a Z shaped impedance network is included between the source and the power circuit. Z-source inverter can boost dc input voltage without requiring DC-DC boost converter or step up transformer, hence overcoming output voltage limitation of traditional voltage source inverter [3].

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The conventional VSI and CSI suffer from the limitation that triggering two switches in the same leg or phase leads to a source short and in addition, the maximum obtainable output voltage cannot exceed the dc input, since they are buck converters and can produce a voltage lower than the dc input voltage. Both Z-source inverters and quasi-Z-source inverters overcome these drawbacks; by utilizing several shoot-through zero states. A zero state is produced when the upper three or lower three switches are fired simultaneously to boost the output voltage. The inclusion of the shoot through state makes this topology superior and reliable and the extension of this inverter is quasi-Z-source inverter (qZSI). The qZSI topology comprises of passive components such as inductors, capacitors, diodes and a three phase inverter with six switching devices. The voltage gain ratio of q ZSI has wide range and the current drawn from the source is constant. In addition to this, the reliability of this topology is high due to the presence of shoot through state. So, qZSI topology is better compared to Z-source inverter. But it encounters a heavy in rush current during start up and has boost factor [4]. This provides a unique feature, such as voltage sag, reduced line harmonics, improve power factor, reliability and extended output.

Three-phase induction motors have been the main consideration in industries more than single phase induction motors due to certain parameters such as; efficiency, torque ripples and power factor. In places like rural areas to be use of rolling mills, machine tools and in low power industrial application for robotics, where by a three-phase utility may not be available, high performance converters must be used to run three-phase induction motor. Low losses and cost-effectiveness of these converters are very important [5]. Induction Motors are extensively used in industries for the replacement of DC motor systems and low power drive systems due to the advantages such as simple construction, rugged, high torque to weight ratio, high reliability and high power density. Extensively available various horse power rating and power rating. MATLAB/SIMULINK is used for carrying out the simulation studies. Performance parameters of the QZSI fed and induction motor in open loop control is investigated and the results are discussed.

Existing System

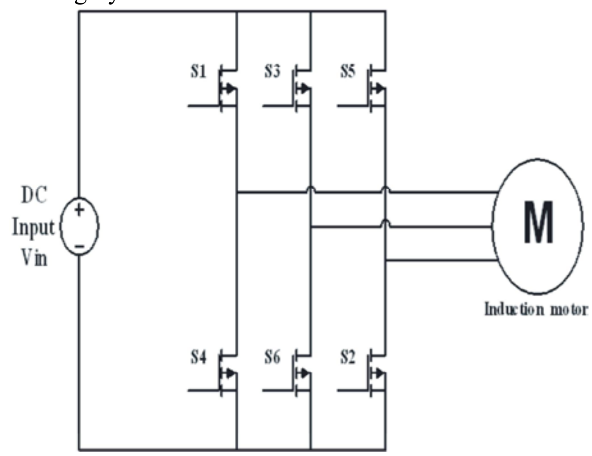

Fig. 1: Block diagram of existing system

In existing system, dc source is converted into three phase AC by using inverter. The three phase inverter which consist of six semi-conductor switches (MOSFED) is used. MOSFED are high voltage, low current capability so it extensively used. The converted AC voltage is given to the induction motor input.

The circuit diagram of qZSI fed induction motor is shown in Fig. 2. The q-ZSI impedance network provides high voltage boosting capability which runs the induction motor without adding any boosting converter circuits. The shoot through technique will improves input voltage duty ratio and doubles the output voltage. The switching pulses for the proposed inverter are obtained using pulse amplitude modulation method. Switching stress are reduced due to the presence of impedance network which deliver higher efficiency.

Proposed System

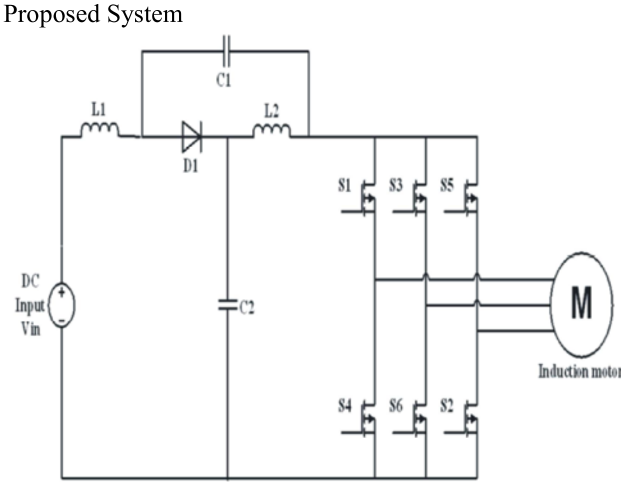

Fig. 2: Block diagram of proposed system

The Objectives to Be Achieved by the Proposed System:

- Desired stable output power to the induction motor
- Boost-buck function by the one-stage conversion.
- Continuous input current (input current never drops to zero, thus featuring the reduced stress of the input voltage source, which is especially topical in such demanding applications as power conditioners for fuel cells and solar panels).
- Excellent reliability due to the shoot-through withstanding capability.
- Low or no in-rush current during start up.

Operating Principle and Equivalent Circuit of qZSI: The two modes of operation of a quasi-Z-Source Inverter are:

- Non-Shoot through mode.
- Shoot through mode.

Non-shoot Through Mode: In the non-shoot through mode, the switching pattern for the qZSI is similar to that of a VSI. The inverter bridge, viewed from the DC side is equivalent to a current source. The input dc voltage is available as DC link voltage input to the inverter, which makes the qZSI behave similar to a VSI. The Non-shoot through mode is shown in Fig. 3.

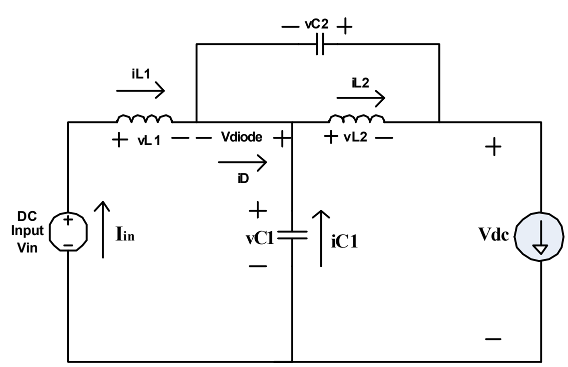

Fig. 3: Equivalent circuit of QZSI in Active mode

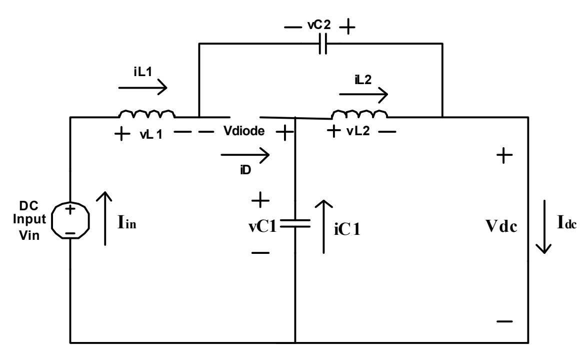

Fig. 4: Equivalent circuit of QZSI in Shoot through Mode

Shoot Through Mode: In the shoot through mode, switches of the same phase in the inverter bridge are switched on simultaneously for a very short duration. The source however does not get short circuited when attempted to do so because of the presence LC network, while boosting the output voltage. The DC link voltage during the shoot through states, is boosted by a boost factor, whose value depends on the shoot through duty ratio for a given modulation index. The Non-shoot through mode is shown in Fig. 4.

Analysis of Impedance Network: For simplicity, assuming that the inductors L_1 and L_2 and Capacitors C_1 and C_2 have the same value respectively, the Quasi Z-Source network becomes symmetrical. From the symmetry and the equivalent circuits, It is supposed that $L_1= L_2$ and $C_1= C_2$.

The output ac voltage equation of PWM based ZSI is given by:

$$V_{ac} / V_0 / 2 = MB \quad (1)$$

Where, Vac is maximum sinusoidal inverter output voltage, B is boost factor, M is the modulation index and Vo is input dc voltage.

The product (B.M) is called inverter gain and is expressed by G. So, equation (1) can be written as

$$V_{ac} = G*V_0/2 \quad (2)$$

Boost factor is decided from the given relation

$$B= 1/1- 2T_0/T \quad (3)$$

Where T_o is the shoot-through time interval over a switching cycle T. Therefore, in the 3-phase ZSI there are nine permissible switching states – six active states or vectors, two zero states and one extra zero state (when the both devices of any one of the phase leg are gated on) called shoot through state. Assuming that during one switching cycle, T, the interval of the shoot through state is $T0$; the interval of non-shoot-through states is T1;thus one has $T = T_0 + T1$ and the shoot-through duty ratio,

$$D = T_0 / T_1.$$

During the interval of the non-shoot-through states, T_1

$$vL_1 = V_{in} – VC_1, vL_2 = -VC_2 \quad (4)$$

During the interval of the shoot-through states, $T0$,

$$vL_1 = VC_2+ V_{in}, vL_2 = VC_1 \quad (5)$$

$v_{PN} = 0, v_{diode} = VC_1 + VC_2$ (6)

At steady state, the average voltage of the inductors over one switching cycle is zero.

$V_{PN} = VC_1 - vL_2 = VC_1 + VC_2, v_{diode} = 0$

Inductor Design: During traditional operation mode, the capacitor voltage is always equal to the input voltage. So there is no voltage across the inductor. During shoot through mode, the inductor current increases linearly and the voltage across the inductor is equal to the voltage across the capacitor.

The average current through the inductor is given by,

$IL = P/V_{dc}$ (7)

Where P is the total power and Vdc is the input voltage. The average current at 1kW and 150 V input is

$IL_{(avg)} = 1000/150 = 6.67A$

The maximum current occurs through the inductor when the maximum shoot-through happens, which causes maximum ripple current. In this design, 30% current ripple through the inductors during maximum power operation was chosen. Therefore the allowed ripple current was 4A and maximum current is 10.67A.

For a switching frequency of 10 kHz, the average capacitor voltage is

$V_C = (1-T_O/T) * V_{dc} / (1-2T_O/T)$ (8)

Substituting the values in the above equation (5) the average capacitor voltage is 300V. So the inductance must be no less than

L = 0.1 * 10 * 300/10.67 = 3Mh

Capacitor Design: The purpose of the capacitor is to absorb the voltage ripple and maintain a fairly constant voltage. During shoot-through the capacitor charges the inductors and the current through the capacitor equals the current in the inductor. Therefore the voltage ripple across the capacitor is

$V_C = IL_{(avg)} T_S/C$ (9)

The capacitor voltage ripple is 0.17%. Substituting the above values in the equation the required capacitance was found to be

C = 6.67 * 0.1 * 10 (300 *0.0017) = 100µF

Hence the impedance network of the Quasi-Z-Source Inverter which consists of the value of inductor is 3mH and capacitor is 100µF.

RESULTS AND DISCUSSION

To confirm the above analysis of Quasi Z-Source Inverter fed induction motor in open loop is simulated using MATLAB/SIMULINK. The parameters for the system are Phase = 3φ, Voltage = 220V, Current= 10amps, Speed = 3000RPM, Stator phase resistance = 2.8Ω and stator phase inductance = 8.5mH. Two control loops are

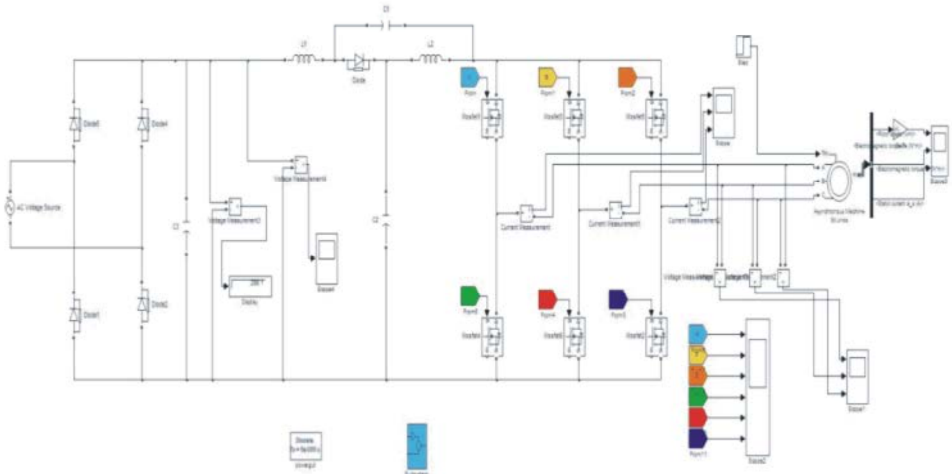

Fig. 6.1: QZSI fed induction Motor with open loop control

used. The inner loop synchronises the inverter gates signals with the electromotive forces. The outer loop controls the motor's speed by varying the DC voltage. The impedance network parameters are $L_1=L_2=3\mu H$ and $C_1=C_2=100\mu F$, switching frequency: 50 kHz. The simulation model of open loop control of the induction motor which can be according to the pulses are given to the motor drive. The given pulses is used to produce PWM wave by comparing sine wave and triangular wave and is given to the QZSI. The open loop control of quasi-Z-source inverter fed three phase induction motor is shown in Fig 6.1.

The switching pulses for QZSI fed induction motor are shown in Fig. 6.2 which represent the pulse generation circuit. The pulse triggers are generated from the above controller using the shoot through pulses obtained from inverter. The output pulses are given to six MOSFET switches.

The output voltage and current waveforms of QZSI are shown in Fig. 6.3 and 6.4 respectively. The input voltage is 220V and the obtained output voltage of the QZSI is 440V. This Voltage is applied to the three phase Induction Motor. The time response of line voltage of q-ZSI fed induction motor is shown in Fig. 6.3.

The Fig 6.4 shows the output current waveform of QZSI with IM Load. The IM has a no-load starting current of about 50amps and gradually decreases to 5amps. When the load is applied to the motor the load current increase from 5 amps to 10 amps.

Simulation output for speed, torque and stator current are shown in Figure 3.18. At no-load condition speed, torque and stator current are 1500RPM, 0.1Nm and 5amps respectively. The IM is loaded at 0.5seconds with a load disturbance of 10Nm.

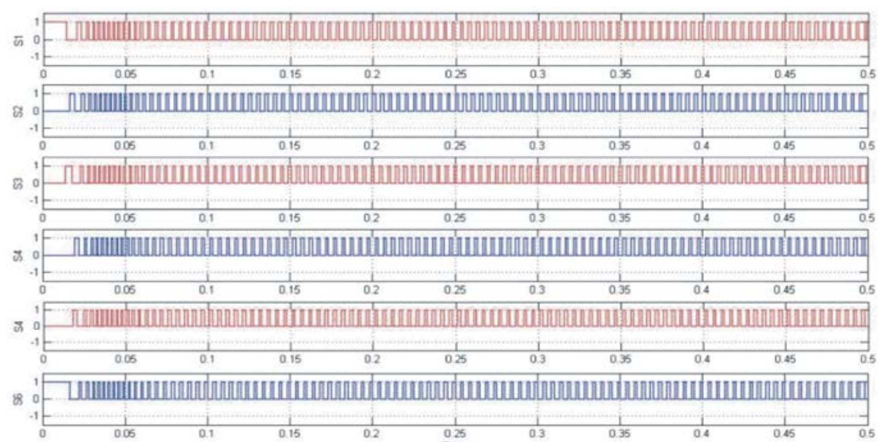

Fig. 6.2: Switching pulses waveform

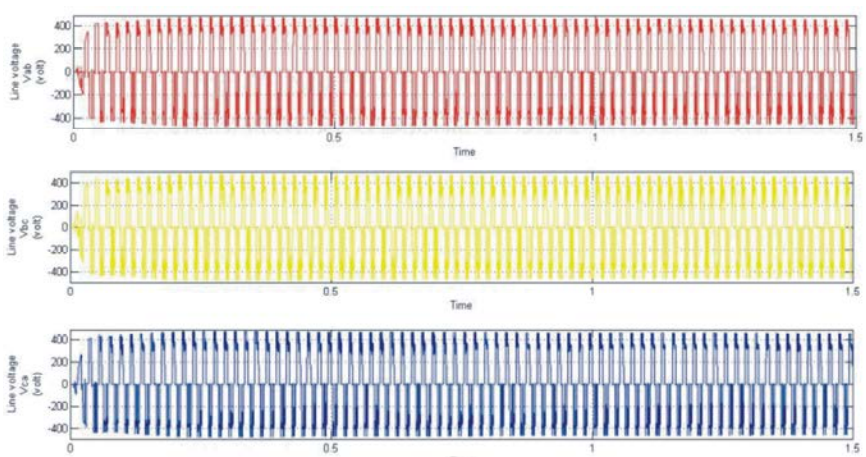

Fig. 6.3: time response of line voltages

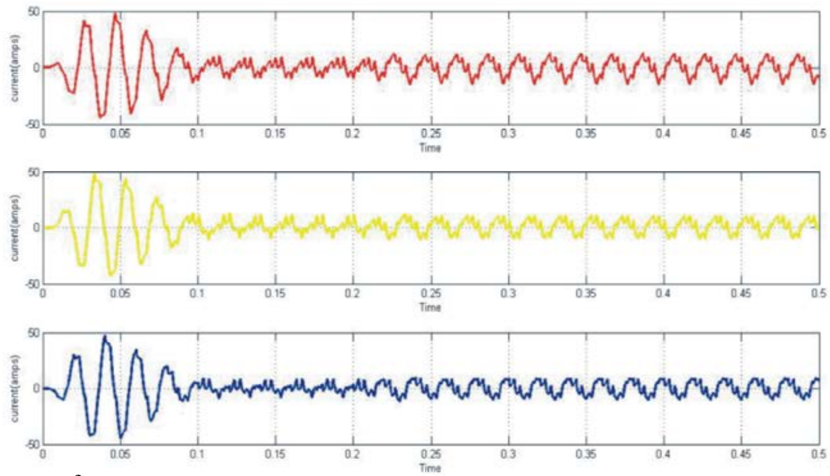

Fig. 6.4: Time response of stator current.

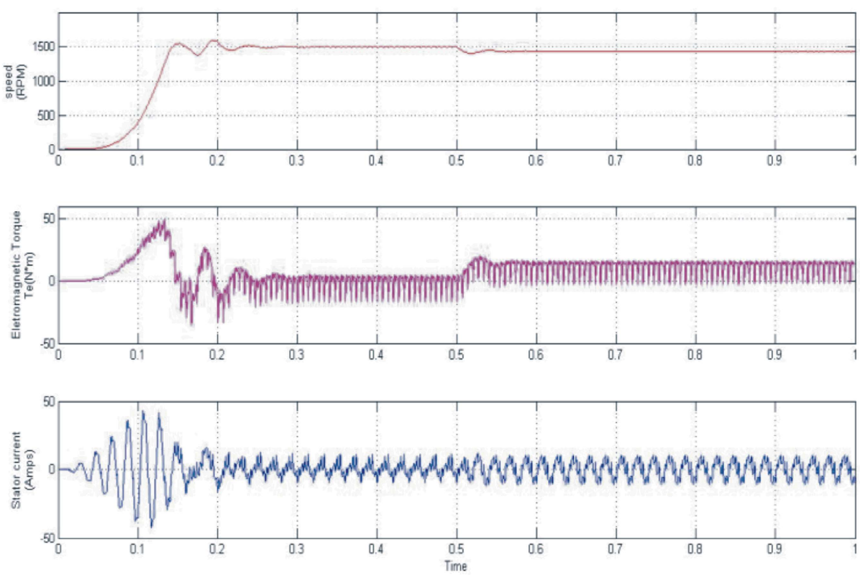

Fig. 6.5: Time response of speed and Electromagnetic Torque

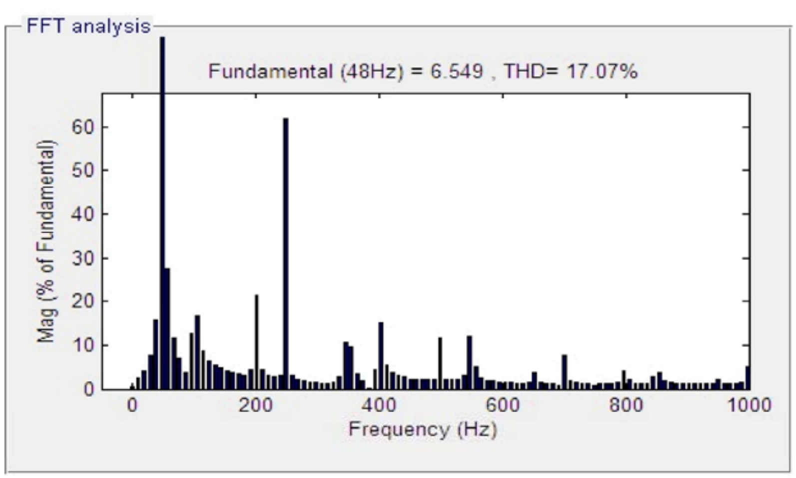

Fig. 5.6: FFT spectrum of stator current of QZSI fed PMBLDC motor.

Table 1: summary of THD values.

Inverter type	THD values (%)
Traditional inverter	51.79%
QZSI fed IM with open loop control	17.07%

Then the parameter for speed, torque and stator current has changed to 1450 RPM, 12Nm and 10amps respectively. At time 0.55 seconds the steady state error is for the IM is reduced to zero and the parameter for speed is changed to 1495 RPM.

The Stator current spectrum for the voltage source inverter fed induction motor with open loop condition is shown in Fig. 6.6: For a fundamental frequency of 48Hz the obtained THD is 17.07%.

Summary of THD values is shown in Table below. The table which represents the THD value comparison of traditional inverter, Z-source inverter and Quasi-Z-source inverter. QZSI fed induction motor which produces lower harmonics. The THD value of Quasi Z-Source Inverter is one third of the value of traditional inverter.

CONCLUSION

In the presented work, efforts are taken to design and simulate a Quasi Z-source Inverter fed induction motor. By utilising a non-linear SPWM technique to generate require sinusoidal voltage at the higher output voltage. The input current ripple reduced and no need for additional filtering circuit. Improved shoot through technique which reduces the switching stress of the inverter. The simulation of qZSI fed Induction motor drive system was presented. The THD% of Quasi ZSI is reduced to one third value comparatively lower than traditional VSI systems. The QZSI system produces good dynamic response with minimum steady state error. Furthermore, this quasi z-source is suitable for renewable energy sources like PV panel, WECS and fuel cells.

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