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Simulation of Single Phase Matrix Converter as a Direct AC-AC Converter with Commutation Strategies

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ABSTRACT:- **This paper is concerned on investigations in implementations of the Single-Phase Matrix Converter (SPMC) as a direct AC-AC converter subjected to passive load conditions. The output voltage was synthesized using the well-known Sinusoidal Pulse Width Modulation (SPWM) technique. A Field Programmable Gate Array (FPGA) was used to implement the controlling algorithm with IGBTs as power switching device. Prior to hardware implementation, simulations were performed to predict the behaviour. The theoretical basis of each algorithm is explained in detail and its performance is tested with simulations implemented in MATLAB/SIMULINK.**

I. INTRODUCTION:

Numerous modern industry applications, from low to high power areas, demand ac signals with adjustable amplitude and frequency. The variable ac signals are achieved through ac/ac power conversion from utility ac signal with fixed amplitude and frequency. Power converters transform frequency and amplitude of ac signals according to system requirements. The most traditional topology in today's off-the –shelf ac/ac power converter is a pulse width modulated voltage source inverter (PWM-VSI) with a front end diode rectifier and a dc-link capacitor. The diode rectifier based PWM-VSI shown in Fig. 1.1 has been the workhorse of the ac/ac power conversion for nearly 30 years [1]-[4]. This structure is comprised of two power conversion stages and intermediate energy storage element. The diode rectifier converts the fixed ac signal in the utility to uncontrolled dc signal. The converted dc power signal is, then stored in the dc-link capacitor. The PWM-VSI subsequently generates ac signals with arbitrary amplitude and frequency, using high-frequency switching operation. This configuration is based on indirect power conversion because the entire ac/ac conversion is performed through intermediate dc power conversion with dc-link between the two ac systems. The dc-link capacitor decouples two ac power conversion stages and ensures the independent control of two stages.

In recent years, significant advances in power semiconductor device technology, low-cost, high-speed control processors, and Matured PWM algorithms have led to a number of modern ac/ac converter topologies.

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In recent years, significant advances in power semiconductor device technology, low-cost, high-speed control processors, and Matured PWM algorithms have led to a number of modern ac/ac converter topologies. The trends for modern ac/ac power converter have been directed to improved utility interface with unity power factor, input current waveforms with minimized harmonics, compact-size converter implementation with low-volume, more integrating silicon structure with reduced passive components, and increased power handling capability with enhanced efficiency for high-power applications [2]. Bearing them in mind, the diode rectifier based PWM-VSI system has several drawbacks caused by its topology and inherent limitation against the modern trends, notwithstanding its wide applications for industry.

II. MATRIX CONVERTER

The Matrix converter is a direct ac/ac power converter, which connects supply ac utility to output ac load through only controlled bi-directional switches. The output ac signals with adjustable magnitude and frequency are constructed by single-stage power conversion process. The direct ac/ac power conversion principle of the Matrix converter leads to the distinct structure with no large dc-link energy storage components. Consequently, the Matrix converter topology can be implemented with compact size and volume compared with the diode rectifier based PWM-VSI, where the dc-link capacitor generally occupies 30 to 50% of the entire converter size and volume. The feature is very promising to the modern low-volume converter trend with high silicon integration. In addition to its compact design, it can draw sinusoidal input currents with unity displacement factor as well as sinusoidal output currents. The converter provides inherent bi-directional power flow capability so that load energy can be regenerated back to the lack of dc electrolytic capacitors, which is very vulnerable in high temperature. The converter also has a long lifetime with no limited-lifetime capacitors [4, 5].

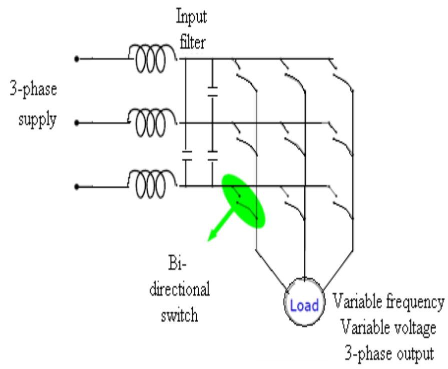

Fig. 2.1 Basic block diagram of a Matrix converter

A three-phase Matrix converter is shown in Fig. 2.1 the converter configuration consists of nine bi-directional switches, which are arranged to connect any of input terminals a, b, and c to any of output lines A, B, and C. Modulation strategies for the bi-directional switches synthesize desired output voltages based on pieces of sinusoidal supply voltages, instead of constant dc voltages of the PWM-VSI.

As the Matrix converter structure is an array of switching devices connecting input source and output load, input and output sides are directly linked, in contrast with the diode rectifier based PWM-VSI separated by the dc-link capacitor. This aspect makes the modulation control of the Matrix converter quite different and complicated, compared to other indirect ac/ac power converters. As a result, modulation techniques to control the

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Matrix converter have been, last two decades, intensively researched and reported since the advent of Venturini's early method [3].

III. SINGLE PHASE MATRIX COVERTER

A single phase Matrix converter converts single phase AC to single phase with variable frequency. The SPMC topology with its 4 bi-directional switches and its individual power switches are as shown in Fig. 3.1 and Fig. 3.2 respectively; each capable of conducting current in both directions, blocking forward and reverse voltages [15-16]. The input and output voltage of the SPMC is given by eq. 3.1 and eq. 3.2 respectively with loads represented in eq. 3.3.

$V_i(t) = \sqrt{2}\,\mathrm{V_i}\sin w_i t$ eq. 3.1

$V_o(t) = \sqrt{2}\,\mathrm{V_o}\sin w_{oi} t$ eq. 3.2

$V_o(t) = Ri_o(t) + L\frac{i_o(t)}{dt}$ eq. 3.3

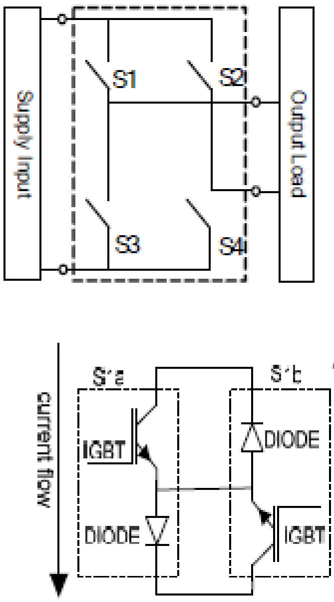


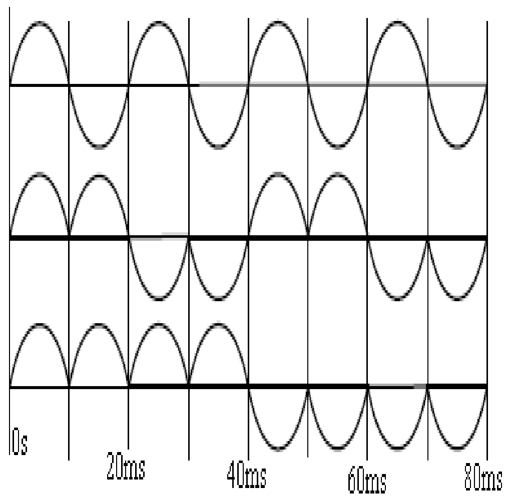
Fig. 3.1 Single phase Matrix converter

3.2 CLASSIFICATION OF MATRIX CONVERTERS

Based on the output frequency the single phase Matrix converters are classified in to two types one is Step down Matrix converter and second is Step up Matrix converter.

3.2.1 Step down Matrix converter

A Step down Matrix Converter has



back to back connected full converters. At any time only one converter is in operation. For the circuit shown in Fig 3.1 when a P – converter operates, positive rectified segments appear across the load, when the N – converter operates, negative rectified segments appear across the load. From the output voltage waveforms shown in Fig 3.3 it can be observed that the output frequency is $1/2^{nd}$ and $1/4^{th}$ of the input frequency. Smaller firing angle delay for the middle pulse and larger delay for the other two pulses is chosen to reduce the harmonics in the output. By selecting two pulses per half cycle, output frequency i.e., ½ the input frequency can be obtained. Thus the output frequency can be varied by varying the number of pulses per

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half cycle. The output voltage can be varied by varying the firing angle delay of the converters.

3.2.2 Step – up Matrix converter

The output frequency of the step up Matrix converter is higher than the input frequency. Fig. 3.4 shows output response of SPWM for 50 Hz to 100 Hz operation and Fig. 3.4 shows output response of SPWM for 50 Hz to 150 Hz operation. It can be seen that the output voltage waveform completes 4 cycles when the input waveform completes one cycle. Thus the frequency of output is four times the input frequency. The disadvantage of this circuit is the requirement of forced commutation.

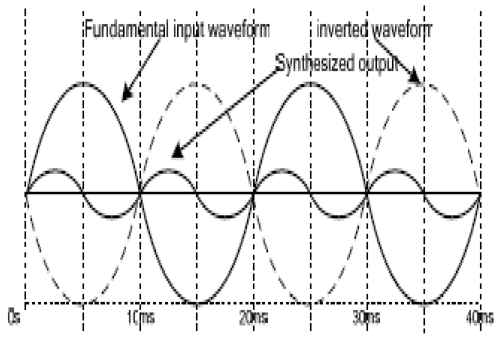

Fig. 3.4 Input 50 Hz to output 100 Hz

3.3 PULSE WIDTH MODULATION CONTROL

The fundamental magnitude of the output voltage from an inverter can be controlled to be constant by exercising control within the inverter itself that is no external control circuitry is required. The most efficient method of doing this is by Pulse Width Modulation (PWM) control used within the inverter. In this scheme the inverter is fed by a fixed input voltage and a controlled ac voltage is obtained by adjusting the on and the off periods of the inverter components. The advantages of the PWM control scheme are:

a) The output voltage control can be obtained without addition of any external components.
b) PWM minimizes the lower order harmonics, while the higher order harmonics can be eliminated using a filter.

The disadvantage possessed by this scheme is that the switching devices used in the inverter are expensive as they must possess low turn on and turn off times, nevertheless PWM operated are very popular in all industrial equipments. PWM techniques are characterized by constant amplitude pulses with different duty cycles for each period. The width of these pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content. There are different PWM techniques which essentially differ in the harmonic content of their respective output voltages, thus the choice of a particular PWM technique depends on the permissible harmonic content in the inverter output voltage.

IV. SIMULINK CIRCUIT FOR SINGLE PHASE MATRIX CONVERTER

The basic simulink circuit diagrams are shown in the Fig. 4.2 (a) and Fig. 4.2 (b) It cnsist of four bi-directional switches, Control circuit, power sypply and the load. The input power supply and the control circuits are designed in the subsystem. The output voltage and the frequency is depends on the control signal which is developed by the control circuit.

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Generaly the load is considerad as single phase Induciton Motor or Resistive and inductive load. The Fig. 4.2 (a) shows single phase Matrix convrter with RL load, and the Fig. 4.2 (b) shows single phase Matrix converter with single phase induction motor. The Fig. 4.1 shows the Gate Control circuit and the current and voltage are measured by Cureent measurement and voltagemeasurements which are selected from the simulink library.

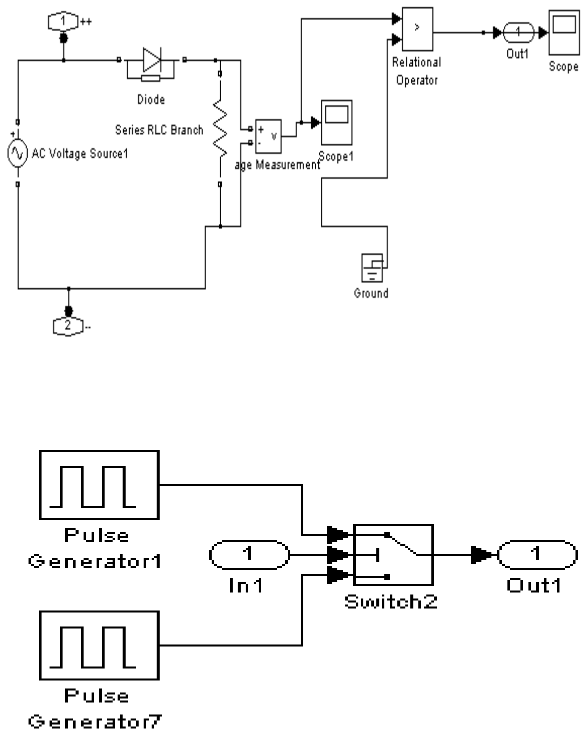

Fig. 4.1 Gate Control Circuit

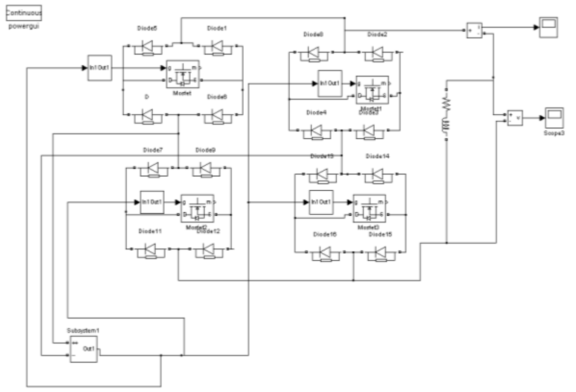

Fig. 4.2 (a) Basic Simulink Circuit with RL load

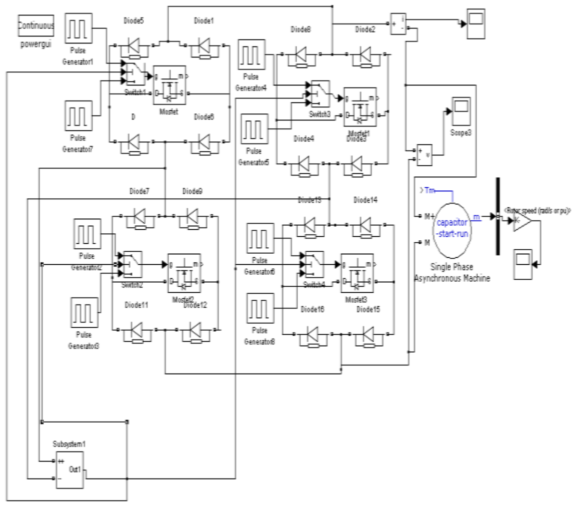

Fig 4.2 (b) Basic Simulink Circuit with Induction Motor load

VI. Simulation Results

The wave forms of a single phase Matrix conveter with different frequency ranges from 12.5 Hz to 400 Hz with R load as shown from Figs. 4.4 (a) and 4.4 (g) respectively.

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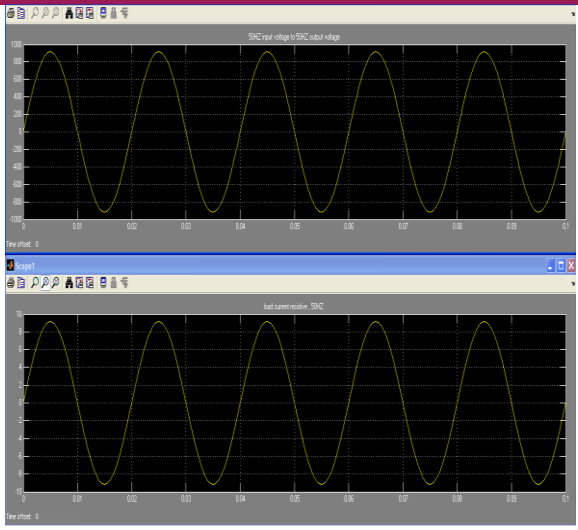

Fig. 4.4 (a) 50 Hz to 50 Hz Output wave from for SPMC with R load

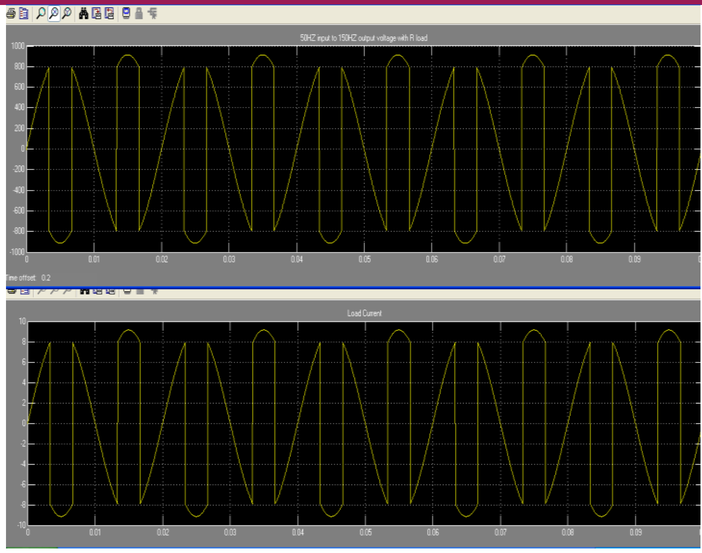

Fig. 4.4 (c) 50 Hz to 150 Hz Output wave from for SPMC with R load

Time

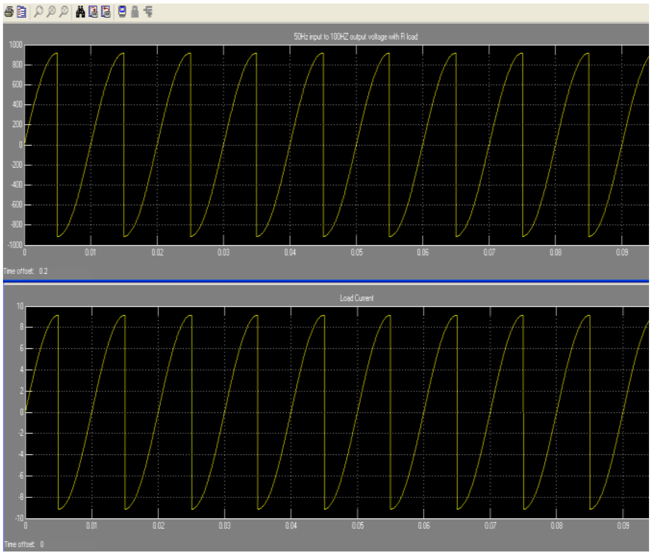

Fig. 4.4 (b) 50 Hz to 100 Hz Output wave from for SPMC with R load

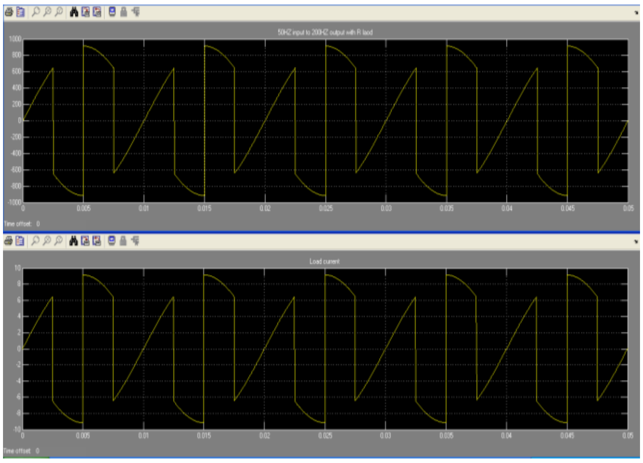

Fig. 4.4 (d) 50 Hz to 200 Hz Output wave from for SPMC with R load

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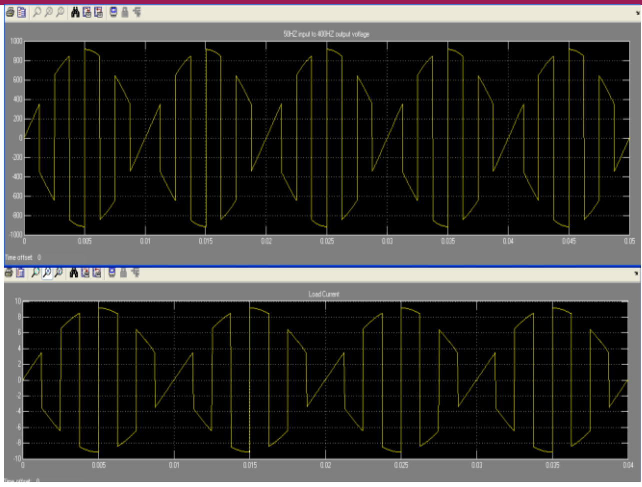

Fig. 4.4 (e) 50Hz to 400 Hz Output wave from for SPMC with R load

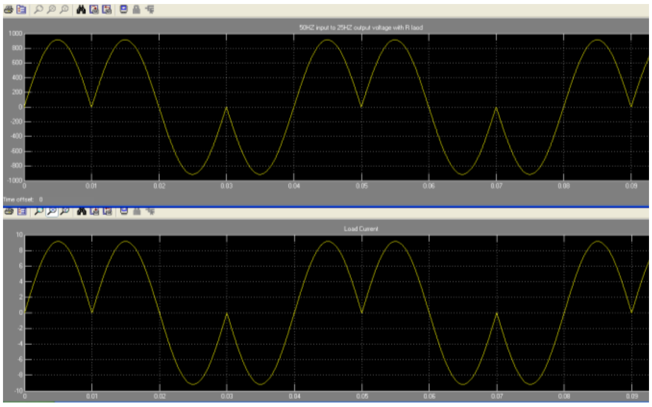

Fig. 4.4 (f) 50 Hz to 25 Hz Output wave from for SPMC with R load

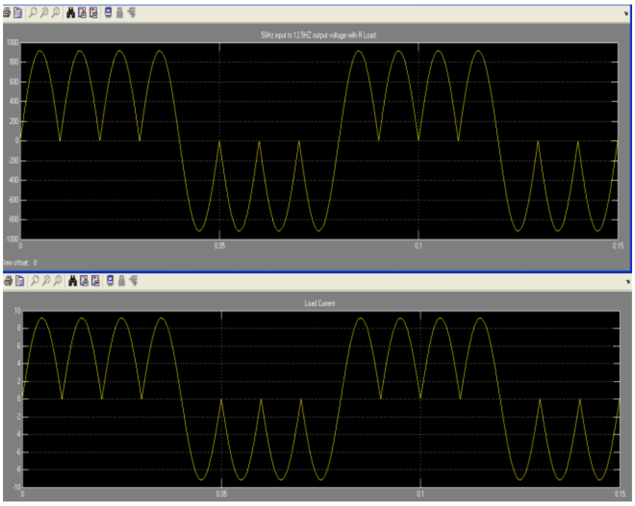

Fig. 4.4 (g) 50 Hz to 12.5 Hz Output wave from for SPMC with R load

VII. Conclusion

In this project, a direct AC-AC converter using single phase Matrix converter with passive load condition was presented without the need of intermediate DC link. Results of the SPMC for both the simulation and experiments illustrates that it is feasible to realize the converter in the various basic AC-AC conversion that includes; AC controller, step-up frequency changer and step-down frequency changer. The safe-commutation technique implemented has resulted in a scheme that allows dead time to avoid current spikes of non-ideal switches and at the same time establishing a current path that could eliminate switching spikes due to the use of inductive load.

Several modulation and control methods have been developed for the Matrix converter, allowing the generation of sinusoidal input and output currents, operating with unity power factor. The most important practical implementation problem in the Matrix converter circuit is the commutation problem between two controlled bidirectional switches, has been solved with the development of highly intelligent multistep commutation strategies.

The simulation results were found to coincide with the theoretical results discussed in Chapter 4. Using AT89C201 Microcontroller and IR2110 driver circuit the control circuit is designed. The control pulses required were generated using CMOS 8-bit Microcontroller with 2K bytes of Flash programmable and erasable read-only memory (PEROM). Depending on the required output frequencies, the program is written in Microcontroller for various switching pulses from 50 Hz to 400 Hz. The hardware results were found to coincide with the simulation results discussed in Chapter 5. Sufficient gate voltage level for triggering the MOSFETs in the Power circuit is obtained by using IR210 driver circuit and provided isolation between the input and output to avoid the short-circuits. The Single Phase Matrix converter has wide range of applications like controlling single phase motors, military, navy, space, communication area especially in telecommunication it can be used as digitally controlled switch mode power supply.

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