ISSN 2278 - 8875
International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
Vol. 1, Issue 5, November 2012

Fuzzy Logic Based Field Oriented Control of Permanent Magnet Synchronous Motor (PMSM)

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ABSTRACT: The Permanent Magnet Synchronous Motor (PMSM) has been widely used in the low to medium power system due to its characteristics of high efficiency, high torque to inertia ratio, high reliability and fast dynamic performance. With the advent of the vector control methods ,permanent magnet synchronous motor can be operated like separately excited dc motor high performance application. The complexity of PI controller tuning and high response time is overcome by Fuzzy controller. Which has less response time and high accuracy without any mathematical calculation .This paper presents a simulation of speed control system on fuzzy logic approach for an indirect vector controlled permanent magnet synchronous drive by applying space vector modulation. The design and analysis of fuzzy logic is studied using MATLAB version 8

KEYWORDS: Fuzzy controller, PI controller, Permanent Magnet Synchronous Motor (PMSM)

I. INTRODUCTION

Permanent Magnet Synchronous Motors (PMSM) have advantages like high efficiency, high power factor, high power density and maintenance free operation, and these motors are nowadays preferred in a variety of applications. Vector controlled PMSM drive provides better dynamic response and lesser torque ripples, and necessitates only a constant switching frequency. The outer speed loop in vector control greatly affects the system performance. Proportional plus integral (PI) controllers are usually preferred, but due to its fixed proportional gain and integral time constant, the performance of the PI controllers are affected by parameter variations, load disturbances and speed variations. These problems can be overcome by the fuzzy logic controllers, which do not require any mathematical model and are based on the linguistic rules obtained from the experience of the system operator. But the performance of the fuzzy controller as compared to the PI controller is superior only under transient

conditions. A simple gain scheduled PI speed controller has been proposed in, where the controller gains are varied with the input error signal. This controller suffers from the drawback that for its proper performance, the limits of the controller gains and the rate at which they would change have to be appropriately chosen. Fuzzy based gain scheduling of PI controller has been proposed in, but the limits of the gains have to be determined by the user manually. [1][6]

II. PRINCIPLE OF VECTOR CONTROL

The invention of vector control in the beginning of 1970’s and demonstrated in induction motor can be controlled by separately excited DC motor, which increase the efficiency of AC drives. Vector control is applicable to both Asynchronous and synchronous motor drive [6]

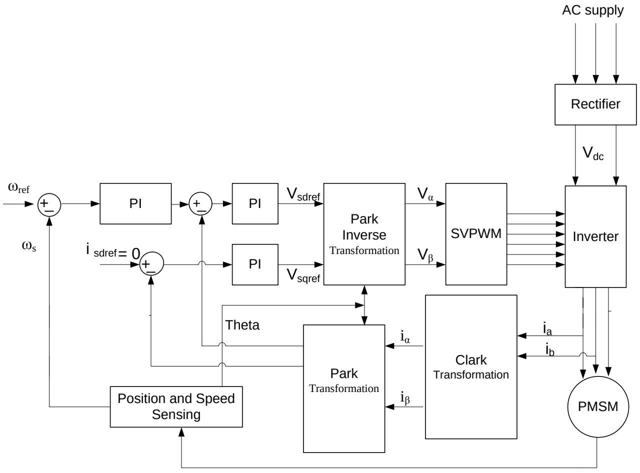

Fig.1 Block diagram for Vector control of PMSM

The synchronous inductance L_s and the corresponding armature flux Ψ_a (=$L_s I_s$) very small, that is, $\Psi_s = \Psi_m = \Psi_f$. For maximum torque sensitivity with the stator current(i.e., maximum efficiency), we can set $i_{ds}=0$ and $I_s = i_{qs}$, as shown in the phasor diagram where the stator resistance R_s is neglected for simplicity. This condition also gives a minimal inverter power rating. The developed torque expression can be easily derived from Equation(1) in the form

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)\psi_f i_{qs} \qquad (1)$$

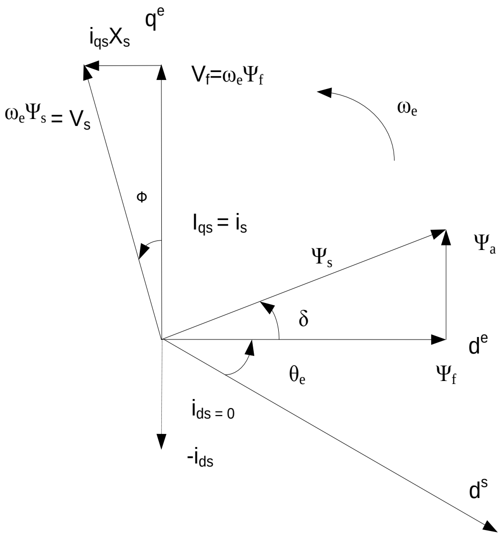

Fig.2 Vector control phasor diagram

Where Ψ_f is the space vector magnitude ($\sqrt{2}\ \Psi_f$) and $\Psi_s \cos \varphi = \Psi_s \cos \delta = \Psi_f$. The equation indicates that the torque is propotional to i_{qs} and the power factor angle φ equals the torque angle δ. fig.2 shows the vector control block diagram for the machine, where the stator command current i_{qs} is derived from the speed control loop. Its polarity is positive for motoring mode, but negative for regeneration mode. The rotating frame signals are converted to stator current commands with the help of unit vector signals ($\cos \theta_e$, $\sin \theta_e$) as shown. The position control loop can be added easily, if desired.[6]

III.PROPOSED SYSTEM:

In traditional PI controller it suffers from overshoot and undershoots of response, when some unknown nonlinearities are present in system. The Fuzzy controller overcomes these disadvantages.[6]

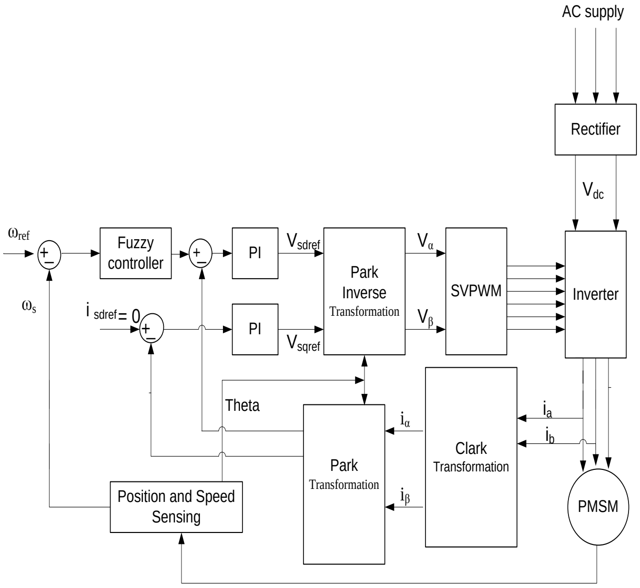

Fig.3 Block diagram for proposed system

The fuzzy logic controller(FLC) executes the rule based taking the inputs and gives the output by defuzzification , inputs are speed error (e) and change in speed error, (ce) the output is torque limit (T^*). Which is equivalent to i_{qs}^* [1-6]

The Clarke transformation is applied to them to determine the stator current projection in the two coordinates αβ-axis (non-rotating frame).

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (2)$$

The Park co-ordinate transformation is then applied in order to obtain this projection in the d, q-rotating frame.

$$\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\cos\theta & \sin\theta \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (3)$$

The d,q projections of the stator currents are then compared to their reference values $i_{sq}*$ and $i_{sd}*=0$ (to get maximum torque, set to zero if there is no field weakening) and corrected by means of PI current controllers. The outputs of the current controller are passed through the inverse Park transform and a new stator voltage vector is impressed to the motor using the space vector pulse width modulation (SVPWM) technique.

In order to control the mechanical speed of the motor, In order to control the mechanical speed of the motor, an outer loop is driving the reference current $i_{sq}*$

The PI regulator compares the speed set point with the measured mechanical speed of the rotor and produces the stator current quadrature axis reference, $i_{sq}*$. That is the speed controller outputs a reference torque, which is proportional to the quadrature-axis stator current component[2]
$i_{sq}*$. The mechanical speed reference is denoted "ω_{ref}". The information about the phase current can be obtained by two current sensors and the information about the rotor position can be obtained by position sensor like incremental encoder.

IV.FUZZY LOGIC CONTROLLER

The fuzzy logic can be considered as a mathematical theory combining multi-valued logic, probability theory, and artificial intelligence to simulate the human approach in the solution of various problems by using an approximate reasoning to relate different data sets and to make decisions.[2][3]

It has been reported that fuzzy controllers are more robust to plant parameter changes than classical PI or PID controllers and have better noise rejection capabilities. The proposed scheme exploits the simplicity of the Mamdani type fuzzy systems that are used in the design of the controller.

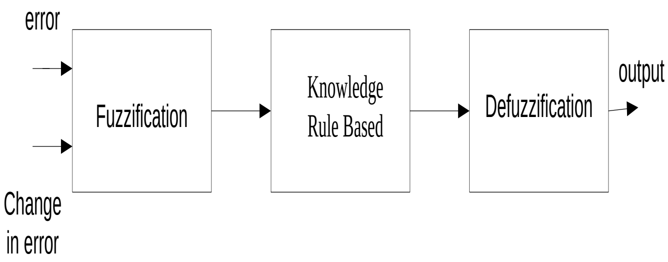

Fig.4 Block diagram for Fuzzy logic controller

A. Membership Functions

The Fuzzy Logic Controller initially converts the crisp error and change in error variables into fuzzy variables and then are mapped into linguistic labels. Membership functions are associated with each label as shown in which consists of two inputs and one output.[4]

Inputs- Triangular membership function
1. Speed error : NE, ZE, and PE.
2. Change in speed error : NCE, ZCE, and PCE.
Output- Triangular membership function
1. Torque Limit : NT*, ZT*, and PT*.

The linguistic labels are divided into three groups. They are: N-Negative, Z-zero, P-positive. Each of the inputs and the output contain membership functions with all these three linguistics. This method of formulation of control algorithms allows implementing heuristic strategies. A straightforward source of deriving the linguistic control strategies are human experience and understanding, which essentially contain the model of the control system in an implicit form.[2]

INPUTS

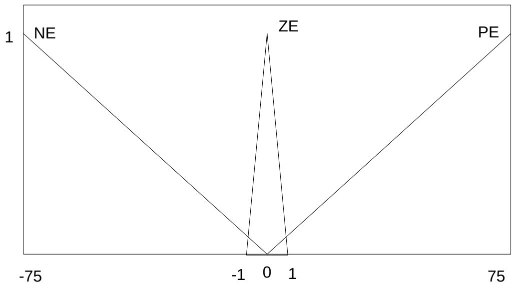

Fig.5 Speed error

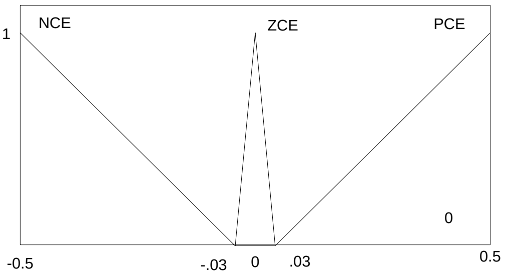

Fig.6 change in speed error

OUTPUTS

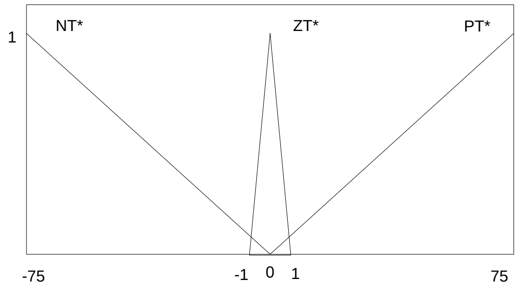

Fig.7 Torque Limit

RULES:

	NE	ZE	PE
NCE	NT	NT	ZT
ZCE	NT	ZT	PT
PCE	ZT	PT	PT

TABLE 1

B. Knowledge Rule Base

The mapping of the fuzzy inputs into the required output is derived with the help of a rule base as given in Table 1.Each rule of the FLC is characterized with an IF part, called the antecedent, and with a THEN part called the consequent. The antecedent of a rule contains a set of conditions and the consequent contains a conclusion. If the conditions of the antecedents are satisfied, then the conclusions of the consequent apply. Considering the first rule, it can be interpreted as: IF change in speed error is N and change is speed is N, THEN the output will be N.[7][8]`

C. Defuzzification

Generally the output obtained is fuzzy in nature and has to be converted into a crisp value by using any Defuzzification technique.[2]

V.RESULTS AND DISCUSSION:

The comparative results of traditional PI controller and Fuzzy logic controller was performed using matlab version 8, results are shown Fig.8, 9, 10, 11,12,13,14 and 15.

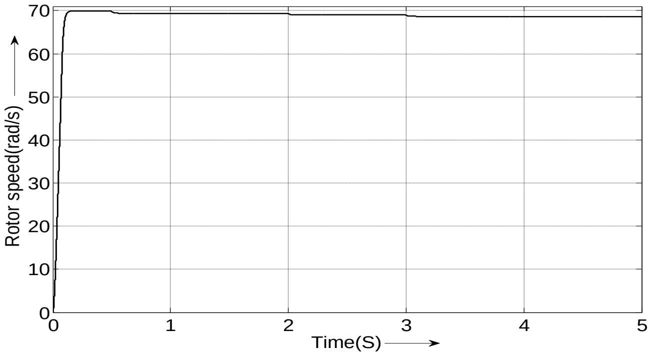

Fig.8 Rotor speed using PI

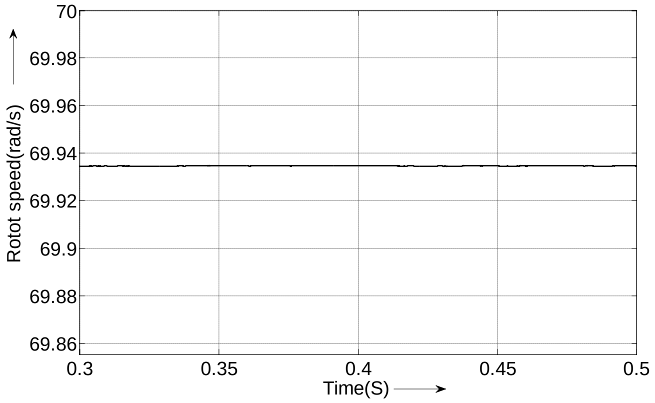

Fig .9 Zoomed Rotor speed using PI-no load

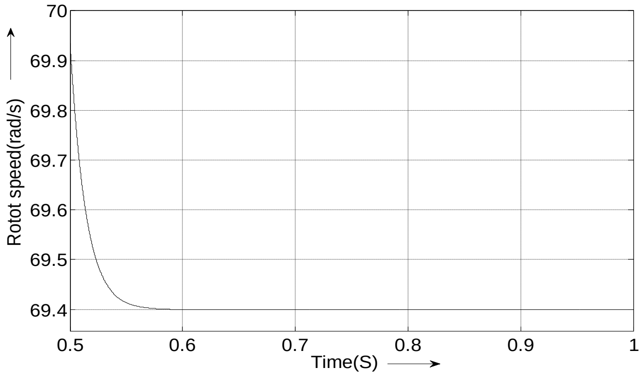

Fig .10 Zoomed Rotor speed using PI- load

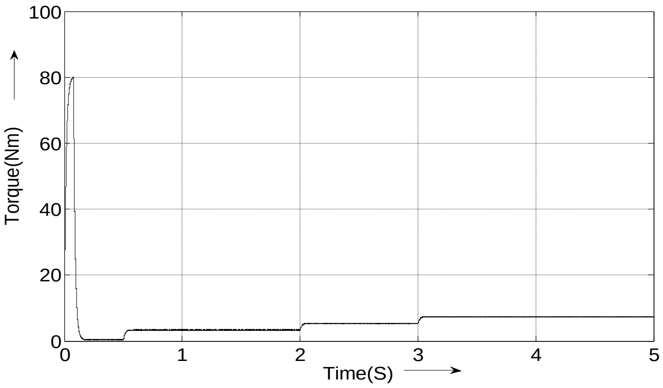

Fig.11 Torque using PI

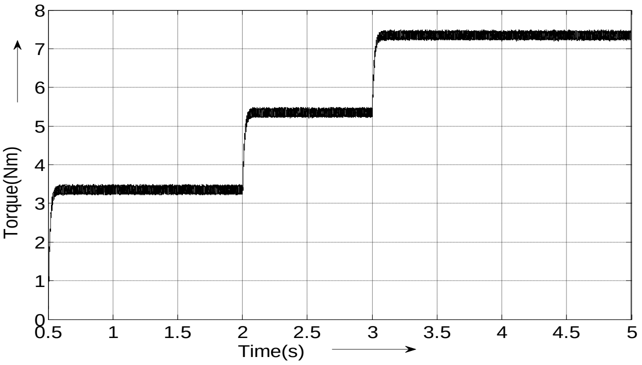

Fig.12 Dynamic Torque using PI

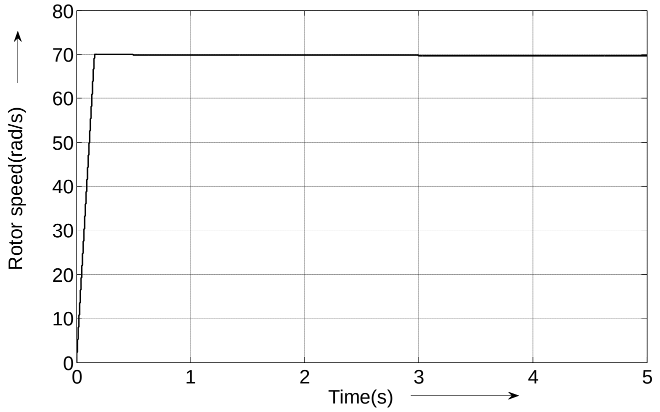

Fig.13 Rotor speed using FLC

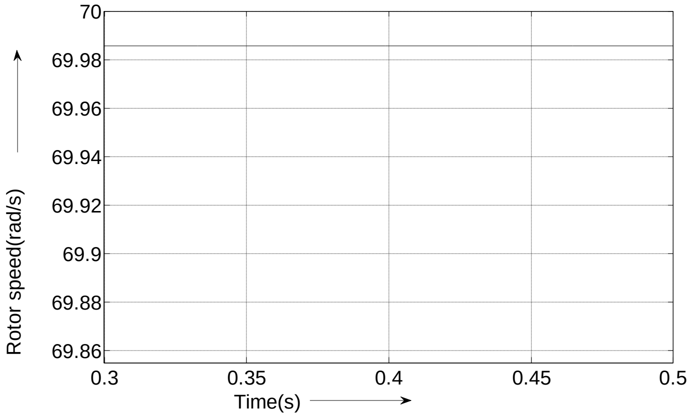

Fig.13 Zoomed Rotor speed using FLC-no load

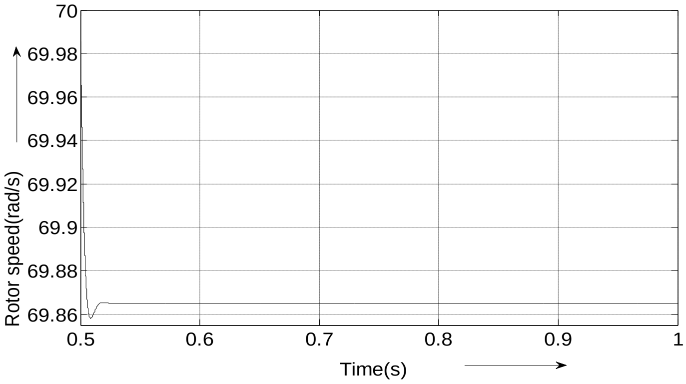

Fig.14 Zoomed Rotor speed using FLC- load

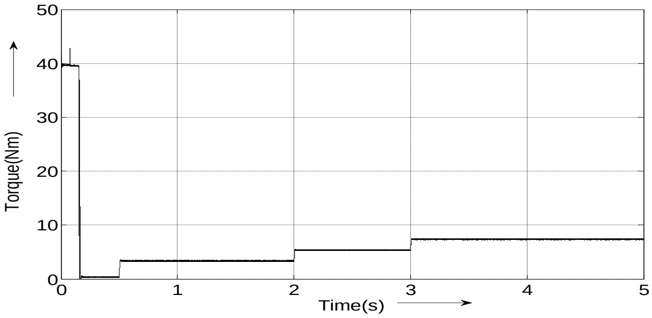

Fig. 15Torque using FLC

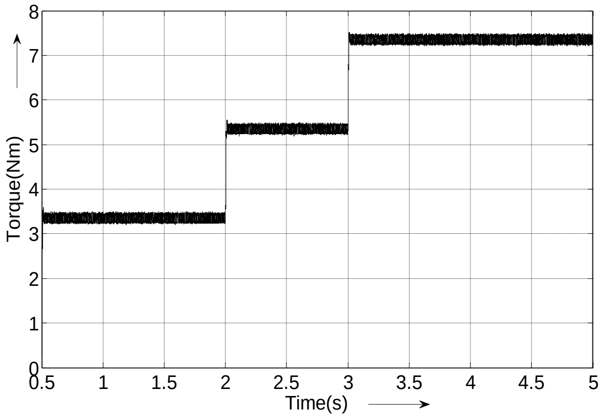

Fig. 15 Dynamic Torque using FLC

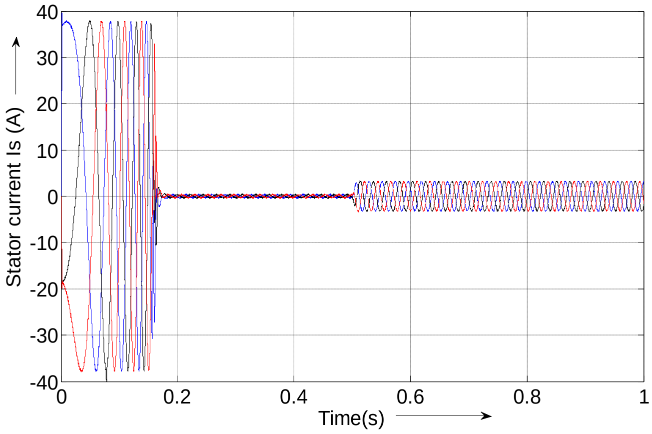

Fig.16 Stator Current using FLC

From the rotor speed waveforms of PMSM controlled by traditional PI fig (12) and FLC fig (15) it is inferred that the dynamic response time is reduced. From the zoomed speed waveforms of fig (9) and fig (13) it is inferred that the steady state error at no load has been reduced from 0.06 rad/s to 0.005rad/s and From the zoomed speed waveforms of fig (10) and fig (14) the steady state error at load it has been reduced from .6rad/s to .14rad/s The initial starting torque of the machine is reduced so the initial stator current drawn by the motor is also reduced from the fig (11) and fig (15)

VI.**CONCLUSION**

A fuzzy rule-base design of fuzzy logic speed control has
been studied for speed control of vector controlled PMSM Drive. A set of fuzzy decision rules are formulated based on the literature review of the controller's design. In this paper, comparative results for traditional PI controller and Fuzzy logic controller for speed response during start-up under no load, load disturbance and changes in command settings. The
Simulation study is realized in MATLAB environment. The investigation of fuzzy controllers is carried out based on several selected speed response. The work can be upgraded to sensorless speed controller by using speed and postion estimators.

APPENDIX

MOTOR PARAMETERS

Type	PMSM
Rated speed	75(rad/sec)
Number of phases	3
Number of poles (P)	8
Base current	8 A
Rated voltage	300 V
Stator resistance per phase(R)	0.9585 ohm

q-axis inductance(Lq)	0.00525 H
d-axis inductance (Ld)	0.00525 H
Stator flux linkages per phase due to rotor magnet (A f)	0. 1827V/ (rad/s)
Moment of inertia (J)	0.0006329Kg/m^2
Friction Factor (F)	0.0003035(N.m.s)

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