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State Feedback Controller Based Imperialist Competitive Algorithm for Load Frequency Control Problem

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Abstract

A major issue in the power system design and operation is Load Frequency Control (LFC). For solving load frequency control problem a new method is proposed considering the state feedback controller based on Imperialist Competitive Algorithm (ICA). In this solution, an objective cost function is used to design the gains of the state feedback matrix. The frequency deviation and power flow variations between the two area is decreased by the proposed cost function. For minimizing the proposed cost function the ICA algorithm is considered. The proposed method evaluation is done by applying the design controller to a two area power system with considerations regarding governor saturation and the results are compared to the one obtained by a classic PI controller. Simulation results show better operation and improved system parameters such as settling time and step response rise time using the proposed approach.

Keywords: Load frequency control, imperialist competitive algorithm, state feedback controller

Introduction

The Load Frequency Control (LFC) has been one of the major issues in electric power system design and operation and is becoming much more significant recently in accordance with increasing size, changing structure and complexity of modern interconnected power systems.

The primary objective of the LFC in an interconnected power system is to maintain reasonably uniform frequency for dividing the load between generators of each area and to keep the tie-line power interchanges to permissible limits in the presence of modeling uncertainties, system nonlinearities and area load disturbances[1]. In the new restructured power system, load frequency control (LFC) acquires a fundamental role to enable power exchanges, provide better conditions for electricity trading and power system's safe operation[2]. Therefore, it is necessary to design load frequency controller to maintain reliability of the electric power system in an adequate level.

Over the past several years, many control strategies for LFC problem have been proposed and developed by the researchers around the world. The conventional proportional-integral (PI) control is probably the most commonly used technique. The main drawback of this controller is that the dynamic performance of the system is highly dependent on the selection of its gain. Furthermore, due to the nonlinearity of power systems, unpredictability of load variations and errors in the modeling, the operating points of a power system may varies very remarkably and randomly during a daily cycle. As a result, a fixed controller based on classical theory may no longer be suitable in all operating conditions for LFC problem. Thus, to provide an appropriate and efficient controller for the LFC system, various control methods based on optimal control, variable structure control[3], adaptive and self-tuning control[4], robust control[5] and artificial intelligence control[6] have been implemented for the load frequency control of power systems.

More recently, the concepts of Artificial Intelligence (AI) techniques, such as fuzzy logic control (FLC), Artificial Neural Network (ANN) [7] and Biologically Inspired (BI) algorithms[8], were applied to design a LFC in a power system. Improved performance might be expected from these methods, however, these methods require either information on the system states or an efficient online identifier thus may be difficult to apply in practice. Moreover, some of them have a centralized scheme which is not feasible for a large power system because of computational and economical difficulties in implementing this scheme.

ICA is a population-based optimization algorithm inspired by the socio-political process of imperialistic competition and proven its superior capabilities, such as faster convergence and better global minimum achievement. ICA has been used to solve different kinds of optimization problems, such as PID controller design[9], decentralized PID controller design for MIMO systems and parametric optimization of multistage operational amplifiers[10].

This paper investigates the ability of ICA method to design the state feedback load frequency controller of a multi-area power system. The proposed approach is implemented to a two-area interconnected power system with considerations regarding governor saturation. The results obtained by proposed approach are compared with those obtained by classic PI controller reported in the literature. Simulation studies show that the dynamic performance of the proposed controller is considerably desirable.

Overview of ICA

A new evolutionary optimization algorithm derived from the socio-political process of imperialistic competition is Imperialist competitive algorithm (ICA). In contrast to the conventional evolutionary optimization algorithms, ICA has showed its capabilities, such as faster convergence and better global minimum achievement. Flowchart of the ICA is illustrated in figure-1. This algorithm begins with an initial population, resemble to other evolutionary algorithms. Each special population is called a country. Countries with the best fitness value are considered to form the *imperialist states* and the rest to be the *colonies* of these imperialists. Each country is distributed to their states, regarding to the imperialists' power. The power of an empire has relation with its fitness value.

The colonies commence to going toward the relevant imperialist country next to producing initial empire. This movement is a simple model of assimilation policy that was pursued by some imperialist states[11-12-13]. Figure-2 shows the movement of a colony towards the imperialist.

In this movement, θ and *x* are random numbers with uniform distribution as shown in figure-1, 2 and *d* is the distance between colony and the imperialist.

$$x \sim U(0, \lambda \times d) \tag{1}$$

$$\theta \sim U(-\gamma, \gamma) \tag{2}$$

Where λ and γ are arbitrary numbers that modify the area that colonies randomly search around the imperialist.

The total power of an empire is determined by power of an imperialist country and its colonies. In this algorithm, the total power of an empire is calculated by the power of imperialist state plus a percentage of the mean power of its colonies. In imperialistic contest, every empire wants to take possession of colonies of other empires and handle them. Consequently, a gradually reduction in the power of weaker empires and then increase in the power of more powerful ones will accrued.

This competition is done by picking some (usually one) of the weakest colonies of the weakest empires and making a competition among all empires to possess them (that) colonies. In this competition, each of empires will have a likelihood of taking possession of the mentioned colonies, based on their total power. The more powerful an empire, the more likely it will possess these colonies. In other words, the possession probability of the colonies depends on the power of the empires trying to possess them. Any empire that is not able to succeed in imperialist competition and cannot increase its power (or at least prevent decreasing its power) will be eliminated. The imperialistic competition will gradually result in an increase in the power of great empires and a decrease in the power of weaker ones. The power of weak empires will gradually loose and ultimately they will collapse. The above procedures cause that all the countries converge to a state in which there exist just one empire in the world and all the other countries are its colonies.

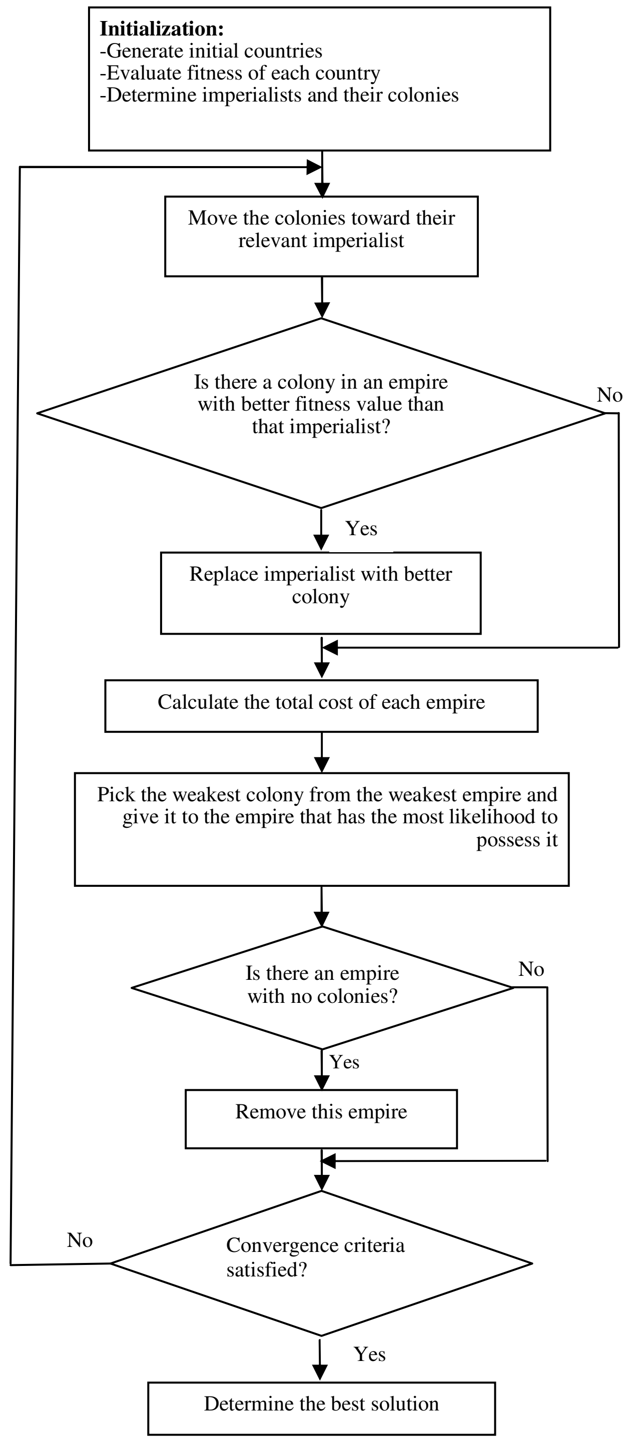

Figure-1
General principle of the ICA

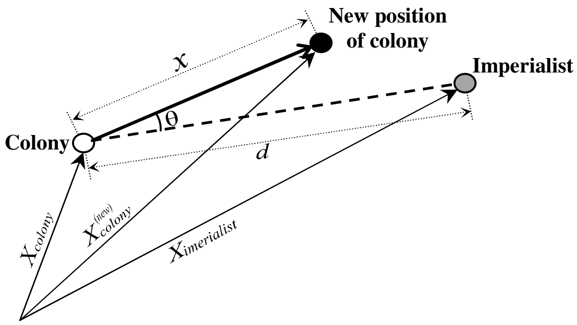

Figure-2
Motion of colonies toward their relevant imperialist

Power System Model

Large-scale power systems naturally consist of complex and multi-variable structures with several interconnected control areas representing coherent groups of generators. Each area has its own generator or group of generators and it is responsible for its native load and scheduled interchange with neighboring areas connected through tie-lines. These tie-lines are utilized for contractual exchange of power between areas and provide support in case of abnormal conditions. In actual power system operations, the load is changing continuously and randomly. As a result, the tie-line power flow and frequency of the area are affected by these load changes at operating point. Therefore, for the satisfactory and stable operation of power system with sudden area small load perturbations and abnormal system parameters these deviations in system frequency and tie-line power should be minimized as quickly as possible. So to ensure the quality of power supply, a load frequency controller is needed to maintain the system frequency at the desired nominal value.

The deviations in frequency and tie-line power are two important variables of interest. The linear combinations of these two variations are known as area control error (ACE). The frequency and interchanged power are kept at their desired values by means of feedback of area control error containing deviation in frequency and error in tie- line power, and controlling the prime movers of generators. The area control error (ACE) for the *i*th area is defined as:

$$ACE_i = \Delta P_{tiei} + \beta_i \Delta f_i \quad (3)$$

Where Δf_i and ΔP_{tiei} are variations in the frequency and variations in the tie-line power from their desired values, in *i*th area, respectively. The goal of control system is to damp these variations to zero as fast and smooth as possible and following a change in the load demand values. Also, β_i is frequency bias constant in area control error equation and should be high enough such that each area adequately contributes to frequency control and can be written as follow:

$$\beta_i = \frac{1}{R_i} + D_i \quad (4)$$

In which R_i and D_i are the regulation constant and damping ratio of *i*th system, respectively.

A two-area interconnected power system with considering governor limiters is considered. Each area has three major components, which are turbine, governor, and generator. The transfer function block diagram of uncontrolled two-area system is illustrated in figure 3. Where Δf_1 and Δf_2 are the frequency deviations in area 1 and area 2 respectively in Hz. Also ΔP_{L1} and ΔP_{L2} are the load demand changes in areas 1 and 2 respectively in per unit (p.u.). Typical data for the system parameters and governor limiters are adopted from[16].

The state-space model of foregoing system can be modeled as multivariable system in the following form:

$$\dot{x} = Ax(t) + Bu(t) + \Gamma d \quad (5)$$

where *x(t), u(t)* and *d* are state, control and load changes disturbance vectors and *A*, *B*, *C* and *Γ* are the system input and disturbance constant matrices associated with above vectors, respectively and represented as equations (6).

Daily load diagram

Maximum daily load at the first day of first month is equal to base load which is presented in table-1. Daily load diagram at the first day of first month is shown in figure-2.

$$x = [\Delta P_{v1}\ \ \Delta P_{m1}\ \ \Delta \omega_1\ \ \Delta P_{Tie}\ \ \Delta P_{v2}\ \ \Delta P_{m2}\ \ \Delta \omega_2\ \ \Delta E_1\ \ \Delta E_2]$$
$$u = [\Delta P_{ref1}\ \ \Delta P_{ref2}] \quad (6)$$
$$d = [\Delta P_{L1}\ \ \Delta P_{L2}]$$

$$A = \begin{bmatrix} \frac{-1}{\tau_{g1}} & 0 & \frac{-1}{R_1 \tau_{g1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{1}{\tau_{T1}} & \frac{-1}{\tau_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{M_1} & \frac{-D_1}{M_1} & \frac{-1}{M_1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & T_{12} & 0 & 0 & 0 & -T_{12} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-1}{\tau_{g2}} & 0 & \frac{-1}{R_2 \tau_{g2}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{\tau_{T2}} & \frac{-1}{\tau_{T2}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{M_2} & 0 & \frac{-1}{M_2} & \frac{-D_2}{M_2} & 0 & 0 \\ 0 & 0 & B_1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & B_2 & 0 & 0 \end{bmatrix}$$

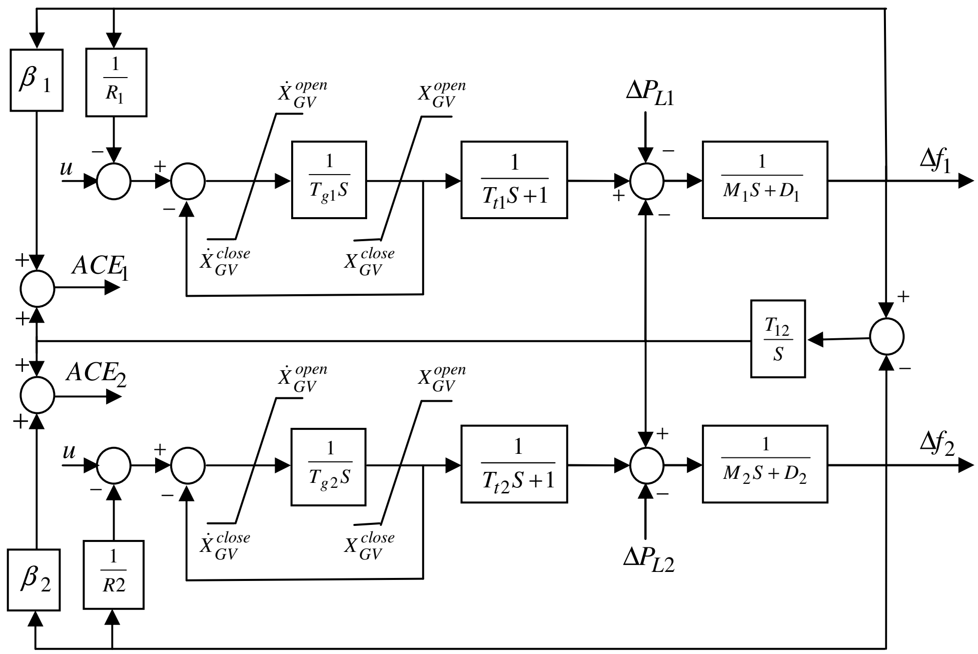

Figure-3
Two-area interconnected power system

$$B=\begin{bmatrix} \frac{1}{\tau_{g1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{\tau_{g2}} & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

$$C=\begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$$\Gamma=\begin{bmatrix} 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T \quad (7)$$

In equation (6), ΔPref1 and ΔPref2 are output of state feedback controller that obtained from following equation:

$$u=\begin{bmatrix} \Delta P_{ref1} \\ \Delta P_{ref2} \end{bmatrix}=-Kx \quad (8)$$

where K is state feedback matrix. To provide a reasonable dynamic performance for the system, tuning of feedback matrix parameters is done in the optimization process by using ICA.

Design of State Feedback Load Frequency Controller Using ICA: The aims are control of frequency and inter area tie- line power with good oscillation damping, also achieving a good performance. Here, we used a proposed cost function introduced in UPFC Modeling in Harmonic Domain[14]. For this, ICA is used to optimize the gains of state feedback controller with a fitness function based on integral of the square of the error (ISE) and the integral of time-multiplied absolute value of the error (ITAE), which are respectively given by:

$$ISE=\int_0^{tf}(ACE_1^2+ACE_2^2)dt \quad (9)$$

$$ITAE=\int_0^{tf}t(|ACE_1|+|ACE_2|)dt \quad (10)$$

The simulations are carried out with the feedback gains obtained from ICA with a fitness function as follow.

$$Fitness=w_1\times ISE+w_2\times ITAE \quad (11)$$

Where w_1 and w_2 are constant coefficient.

A digital simulation is used in conjunction with the ICA optimization process to determine the optimum parameters of state feedback controller for the performance index considered.

In ICA, initial number of countries is set to 100, 10 of which are chosen as the initial imperialists. Also λ and γ are set to 2 and 0.5 (Rad) respectively. The maximum iterations of the ICA is set to 100 convergence of cost function is shown in figure-4.

Simulation Results

A two-control area power system, shown in Fig. 3 is considered as a test system. The typical data for the system parameters and governor limiters for nominal operation condition can be given as follows:
Area #1: M=10, D_1=0.8, T_g=0.2, T_t=0.5, R_1=0.05
Area#2: M=8, D_2=0.9, T_g=0.3, T_t=0.6, R_2=0.0625
and T_{12}=2
Also, the limiter values are
$\dot{X}_{GV}^{open}=0.4$, $\dot{X}_{GV}^{close}=1.5$, $X_{GV}^{open}=1.2$, $X_{GV}^{close}=0.4$

For the sake of comparison, in addition to the proposed control strategy, a conventional PI controller by using the method given in Dynamic Control and Performance of a Unified Power Flow Controller for Stabilizing an AC Transmission System [15]. It was found that $K_{I1}=K_{I2}=0.3$ were the best selections for having the best performance. Using ICA method for LFC design, the following results were obtained for state feedback controller parameters:

$$K=\begin{bmatrix} 0.2646 & 1.766 & 27.8879 & -24.6821 & -0.1778 & -0.4892 & -11.2231 & 5.1120 & -3.9871 \\ -0.1560 & -0.3998 & -14.9952 & 35.9892 & 0.8733 & 3.1873 & 51.8614 & -4.7656 & 5.5638 \end{bmatrix}$$

The designed controllers as two load frequency controller of each area and those obtained by PI controller are placed in the study system (figure 3). To show the effectiveness of the designed controllers, a time domain analysis is performed for the study system. To test the proposed method, a step load change of 0.01 p.u., (i.e. $\Delta P_{L1}=\Delta P_{L2}=0.01$) is applied to the system.

The frequency deviation of both areas and tie-line power variation in nominal condition of the closed loop system are shown in figures 5, 6 and 7 respectively.

By using the presented method, the frequency oscillation and tie-line power changes of two areas following the load changes and are quickly driven back to zero. It should be noticed that although the overshoot of frequency response of classical method shown in figure-4 is more suitable than the presented method, but the settling time of the latter is better than the former. Generally, by referring to figures 4-6 it can be resulted that the proposed method gives a better performance than the classical PI load frequency controller.

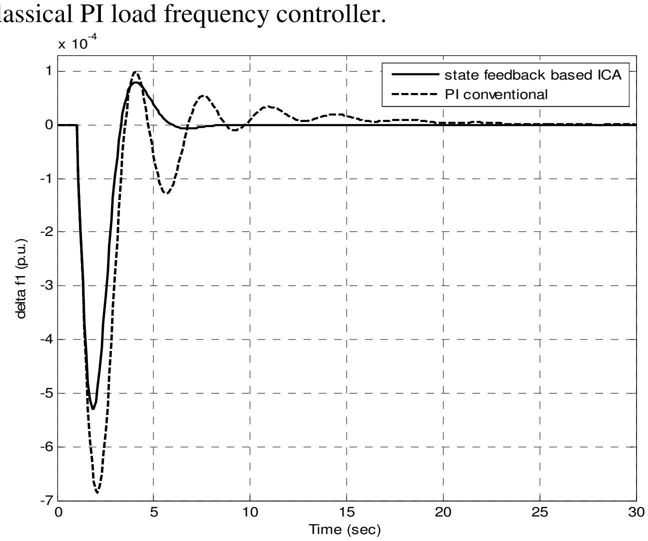

Figure-5
Frequency deviation of area 1

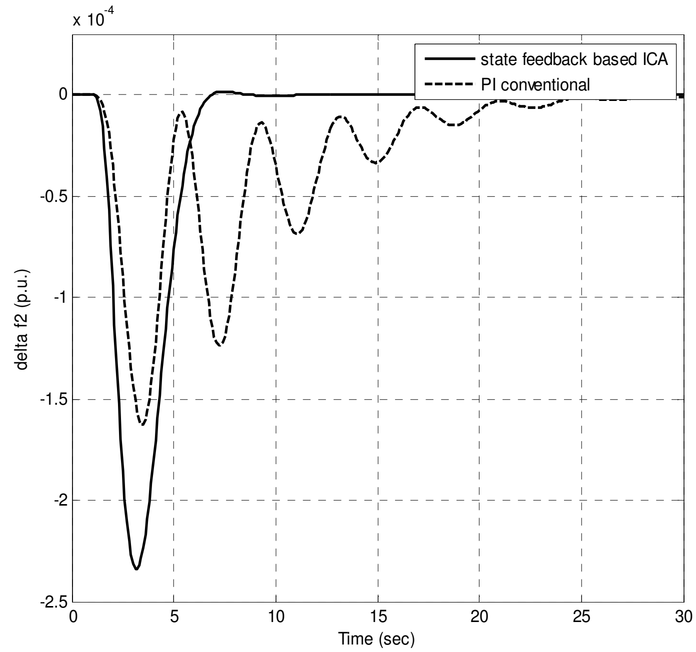

Figure-6
Frequency deviation of area 2

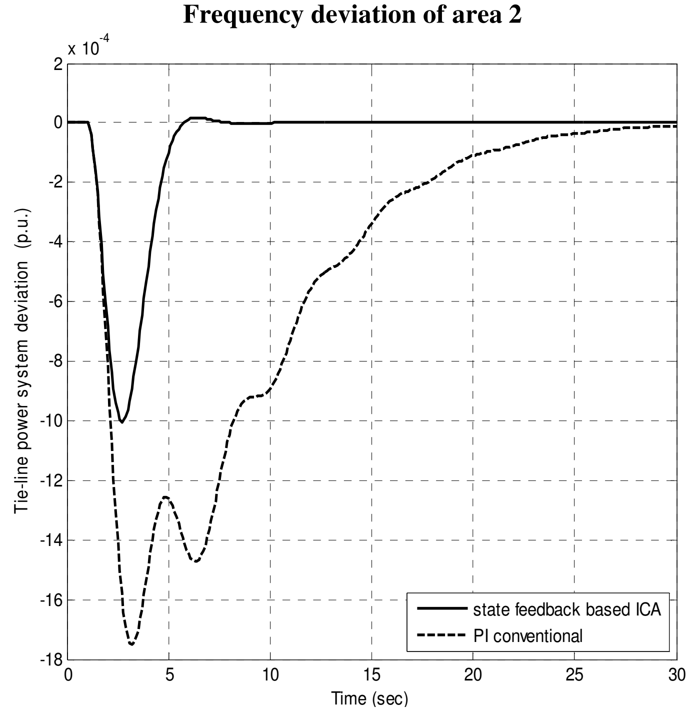

Figure-7
Tie-line power deviation

Conclusion

In this paper a new control system incorporating the state feedback control and imperialist competitive algorithm is used for control of frequency and damping inter area tie-line power variation in a multi-machine power system. The performance of designed controller is tested on a two-area power system with considering governor.

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