Optimum DC motor speed control using PSO technique

Geeta Kumari[1]
Department of Electrical Engg.(SSET),
SHIATS, Allahabad, India
Email: geeta.roy020@gmail.com[1]

Surya Prakash[2]
Department of Electrical Engg.(SSET),
SHIATS, Allahabad, India
Email: sprakashgiri0571@yahoo.com

Abstract: **The aim of this work is to design a speed controller of a DC motor by selection of PID parameters using Particle Swarm Optimization. Here, model of a DC motor is considered as a second order system for armature voltage control method of speed control. In this work pso technique in controllers and their advantages over conventional methods is discussed using MATLAB/Simulink. This proposed optimization methods could be applied for higher order system also to provide better system performance with minimum errors. The main aim is to apply PSO technique to design and tune parameters of PID controller to get an output with better dynamic and static performance. The application of PSO to the PID controller imparts it the ability of tuning itself automatically in an on-line process while the application of optimization algorithm to the PID controller makes it to give an optimum output by searching for the best set of solutions for the PID parameters.**

***Keywords:* -dc motor, Particle Swarm Optimization, PID controller, Parameter tuning.**

I. INTRODUCTION

DC MOTOR

DC motor drives are widely used in applications requiring adjustable speed, good speed regulations and frequent starting, braking and reversing. Some important applications are rolling mills, paper mills, mine winders, hoists, machine tools, traction, printing presses, textile mills, excavators and cranes. Fractional horsepower DC motors are widely used as servo motors for positioning and tracking. DC drives has lower cost, reliability and simple control. The speed of DC motor can be adjusted to a great extent as to provide controllability easy and high performance.The purpose of a motor speed controller is to take a signal representing the demanded speed and to drive a motor at that speed.

PID

Proportional–Integral-Derivative (PID) controllers have been widely used for speed and position control. [17]. They designed a position controller of a DC motor by selection of PID parameters using genetic algorithm (GA) once and secondly by using Ziegler and Nichols method of tuning the parameters of PID controller. They found that the first method gives better results than the second one. Proportional-Integral-Derivative (PID) control technique has been widely used for speed and position control of DC motor.

PID control is a control strategy that has been successfully used over many years. Simplicity robustness, a wide range of applicability.PID control is a fundamental control technology and it makes up 90% of automatic controllers on process control fields.The PID controller calculation (algorithm) involves three separate parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element.

PSO

James Kennedy an American Social Psychologist along with Russell C.Eberhartinnovated a new evolutionary computational technique termed as Particle Swarm Optimization in 1995. The approach is based on the swarm behavior such as birds finding food by flocking. A basic variant of the PSO algorithm works by having population (called a swarm) of candidate solution (called particles). The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered. Here in this technique a set of particles are put in d-dimensional search space with randomly choosing velocity and position. The initial position of the particle is taken as the best position for the start and then the velocity of the particle is updated based on the experience of other particles of the swarming population.Other authors like [5], used a particle swarm optimization (PSO) instead of (GA). They presented a PID controller based on (PSO) method of tuning controller parameters. PSO is one of the modern heuristics algorithms; it wasdeveloped through simulation of a simplified social system, and has been found to

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be robust in solving continuous non-liner optimization problems [4, 5].Particle Swarm Optimization (PSO) is proposed as a solution to the above-mentioned problems and drawbacks. Swarming strategies in bird flocking and fish schooling are used in the PSO and introduced in Kennedy and Eberhart (1995) for optimal designing of controller parameters and defining its best location [1],[18] ,[15].

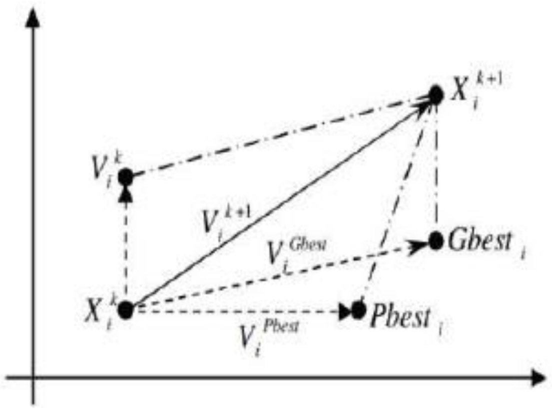

Figure 1:-Modification of searching point by pso

II. MATERIALS AND METHODS

In armature control of separately excited DC motors are used for dc motor modeling.

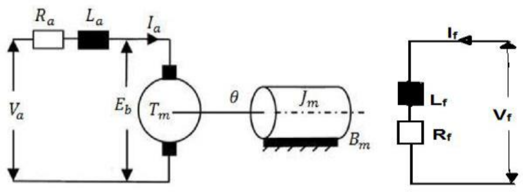

Figure 2: A separately excited DC motor model

MATHEMATICAL ANALYSIS OF DC MOTOR

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + E_b(t) \quad \text{….(1)}$$

$$E_b(t) = K_b\omega(t) \text{….(2)}$$

$$T_m(t) = K_t i_a(t) \quad \text{….(3)}$$

$$T_m(t) - T_L(t) = J_m B_m \omega(t) \text{….(4)}$$

Where,

V_a = armature voltage (V), R_a = armature resistance (Ω), L_a = armature inductance (H), I_a = armature current (A), E_b = Back emf (V), ω = angular speed (rad/sec), T_m = motor torque (Nm) , T_L = load torque (Nm), θ = angular position of rotor shaft (rad), J_m = rotor inertia (kgm2), B_m = viscous friction coefficient (Nms/rad), K_t = torque constant (Nm/A), K_b = Back emf constant (Vs/rad).

Figure 2 showing the basic block diagram of DC motor model including their transfer functions. V_a is the input supply, T_L is load torque and ω is angular speed.

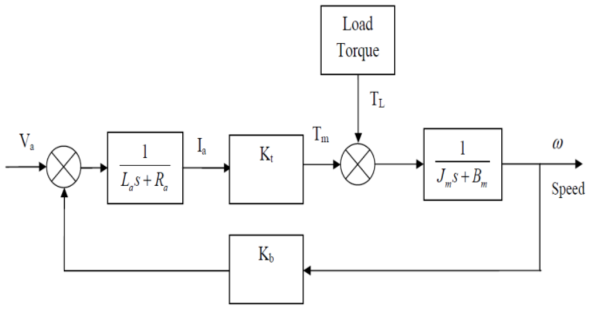

Fig.3 Block diagram of D.C. motor model

Speed Control of DC Motor

Substitute (3) in (2) and (4) in (5), we get

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + K_b\omega(t) \text{ … (5)}$$

$$K_t i_a(t) = J_m \frac{d\omega(t)}{dt} + B_m\omega(t) \quad \text{…(6)}$$

Taking Laplace transform of equation (5) and (6),

$$V_a(s) = R_a i_a(s) + s\, L_a I_a(s) + K_b\omega(s) \text{ ... (7)}$$

$$K_t I_a(s) = s\, J_m\omega(s) + B_m\omega(s) \quad \text{...(8)}$$

There are two possible conditions:

When $T_L = 0$

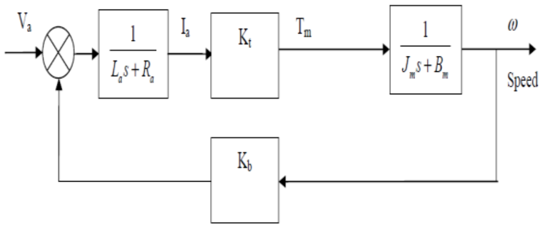

Fig.4 Block diagram D.C. motor model when $T_L = 0$

Figure 3 shows that the DC motor is running under no-load condition (ideal) i.e. $T_L = 0$. Now find the transfer function of ω(s) with respect to Va(s).
So, the relation between motor speed and applied voltage is given by the transfer function,

$$\frac{\omega(s)}{V_a(s)} = \frac{K_t}{L_a J_m s^2 + (R_a J_m + L_a B_m)s + (R_a B_m + K_b K_t)}$$

Motor Parameter and useful formulas

Power P = 8 watts, Speed N = 5000 rpm (max), rotor inertia $\mathbf{J_m}$ is assumed to be 0.01 and Supply voltage Vt = 12 volts. Therefore for the max speed rpm of 5000, it can be calculate the torque constant K;

$$\frac{V_t}{K} = \frac{2\pi N}{60} = \omega_m \quad \text{.... (10)}$$

$\mathbf{K_t}$= 0.023 and ω_m = 524 radsec^{-1}

From equation no.7 as $\frac{d\theta}{dt} = \omega$

$$K_t i_a(t) = J_m \frac{d\omega(t)}{dt} + B_m \omega(t) \ldots (11)$$

At the steady state (used as analyzed data), both **I** and **ω** are stabilized: $\left(\frac{d\theta}{dt} = \omega = 0 \right)$

$\frac{P}{\omega} = T$; Where **W** mentioned as the minimum possible speed to rotate the DC motor, 1200 rpm;

T = 15.27 Nm, Therefore, the total equivalent damping $\mathbf{B_m}$can be chosen the value of;
(0.023*0.663) – $\mathbf{B_m}$(524) = 0
$\mathbf{B_m}$= 0.00003

By calculating and assuming the require data as above, the Motor Model. **Va**=12V; $\mathbf{J_m}$=0.01; $\mathbf{B_m}$=0.00003; **Kt**=0.023; **R** =1ohm; and **L** =0.5H;

The Matlab code for the motor is as follows

```
Kt =.023;
Kb =.023;
R = 1;
L = .5;
J = .01;
b = .00003;
num = Kt;
den=[(J*L)((J*R)+(L*b))((b*R)+Kt*Kb)];
Dcmotor=tf (num, den)
```

III.SPEED CONTROL USING PID TUNING METHODS

The PID controller is the most common general purpose controller in the today's industries. It can be used as a single unit or it can be a part of a distributed computer control system.
After implementing the PID controller, now we have to tune the controller; and there are different approaches to tune the PID parameters like P, I and D. The Proportional (P) part is responsible for following the desired set-point while the Integral (I) and Derivative (D) part account for the accumulation of past errors and the rate of change of error in the process or plant, respectively.

PID controller consists of three types of control i.e. Proportional, Integral and Derivative control

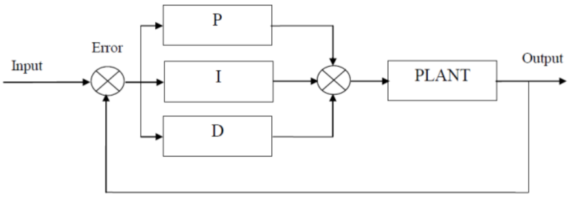

Fig.5 Schematic of PID controller

The system transfer function in continuous s-domain are given as
For $P = K_p , I = K_i / s$ and $D = K_d s$

$$G_c(s) = P + I + D = K_p + \frac{K_i}{s} + K_d s \quad (12)$$

$$G_c(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \quad ..(13)$$

Where K_p is the proportional gain, $K_i$is the integration coefficient and $K_d$is the derivative coefficient.
$T_i$is known as the integral action time or reset time and T_d is the derivative action time or rate time

There are various tuning strategies based on an open-loop step response. While they all follow the same basic idea, they differ in slightly in how they extract the model parameters from the recorded response, and also differ slightly as to relate appropriate tuning constants to the model parameters. There are different methods, the classic Ziegler-Nichols test, and Cohen- Coon test. Naturally if the response is not sigmoid or 'S' shaped and exhibits overshoot, or an integrator, then this tuning method is not applicable.

This method implicitly assumes the plant can be adequately approximated by a first order transfer function with time delay.

$$Gp = \frac{Ke^{-\theta s}}{Ts+1} \quad ..(14)$$

Where K is gain, θ is the dead time or time delay, and T is the open loop process time constant. Once we have recorded the open loop input/output data, and subsequently measured the times T and θ, the PID tuning parameters can be obtained directly from the given tables for different classical methods.

Figure 6. Block diagram of plant with variable output

Ziegler-Nichols Tuning Method

The PID tuning parameters as a function of the open loop model parameters K, T and θ from equation (14) as derived by Ziegler-Nichols.

They often form the basis for tuning procedures used by controller manufacturers and process industry. The methods are based on determination of some features of process dynamics. The controller parameters are then expressed in terms of the features by simple formulas. The method presented by Ziegler and Nichols is based on a registration of the open-loop step response of the system, which is characterized by two parameters. First determined, and the tangent at this point is drawn. The intersections between the tangent and the coordinate axes give the parameters *T* andθ. A model of the process to be controlled was derived from these parameters. This corresponds to modeling a process by an integrator and a time delay. Ziegler and Nichols have given PID parameters directly as functions of *T* andθ.. The decay ratio for the step response is close to one quarter. It is smaller for the load disturbance. The overshoot in the set point response is too large.

Table 1 Ziegler Nichols method

Controller		K_p	T_i	T_d
Ziegler-Nichols Method	**P**	T/Kθ	-	-
	PI	0.9T/Kθ	θ/0.3	-
	PID	1.2T/Kθ	2θ	0.5θ

Algorithm of PSO

The ith particle in the swarm is represented as $Xi = (xi1\ , xi2, xi3, \ldots\ldots\ldots\ldots\ldots\ldots xid)$ in the d-dimensional space.
The best previous positions of the ith particle are represented as:

$$Pbest = (Pbesti,1\ ,Pbesti,2\ ,Pbesti,3 \ldots\ldots\ldots\ldots Pbesti,d\ )$$

The index of the best particle among the group is Gbestd.
Velocity of the ith particle is represented as $Vi = (Vi,1\ Vi,2\ Vi,3 \ldots\ldots\ldots\ Vi,d)$
The updated velocity and the distance from Pbestid to Gbesti,d is given as ;

$$Vi,m^{t+1} = W * Vi,m^{t} + C1 * rand() * \left(Pbesti,m - Xi,m^{t}\right) + C2 * rand() * \left(Gbest\ m - Xi,m^{t}\right)$$

$Xi,d^{(t+1)} = Xim^{(t)} + Vi,m^{(t+1)}$
For i=1, 2, 3.......n.
m = 1, 2, 3.....d.
where,
n:- Number of particles in the group.
d: - dimension index.
t: - Pointer of iteration.
$Vi,m^{(t)}$:- Velocity of particle at iteration i.
W: - Inertia weight factor.
C1, C2:- Acceleration Constant.
rand ():- Random number between 0 and 1.
$Xi,d^{(t)}$:- Current position of the particle ‘i’ at iteration.
Pbest: - Best previous position of the ith particle.
Gbest:- Best particle among all the particle in the swarming population

Objective Function for Particle swarm optimization

```
function F= tightnes (kd, kp, ki)
T=tf([.023*kd .023*kp .023*ki],[.005 (.010015+.023*kd) (.000559+.023*kp).023*ki]);
S=stepinfo (T1);
tr=S.RiseTime;
ts=S.SettlingTime;
Mp=S.Overshoot;
Ess=1/(1+dcgain(T1));
F= (1-exp (-0.5))*(Mp+Ess) +exp(-0.5)*(ts-tr);
```

IV. SIMULINK MODEL OF DC MOTOR

The Simulink model of DC motor using is shown in Fig 7.

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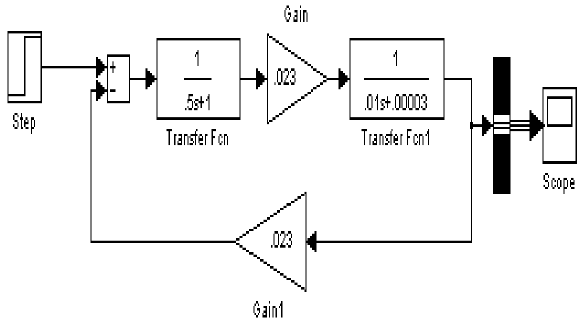


Fig.7 Simulink model of DC motor

The Simulink model of various tuning method for speed control of DC motor using PID controller is shown in Fig 8.

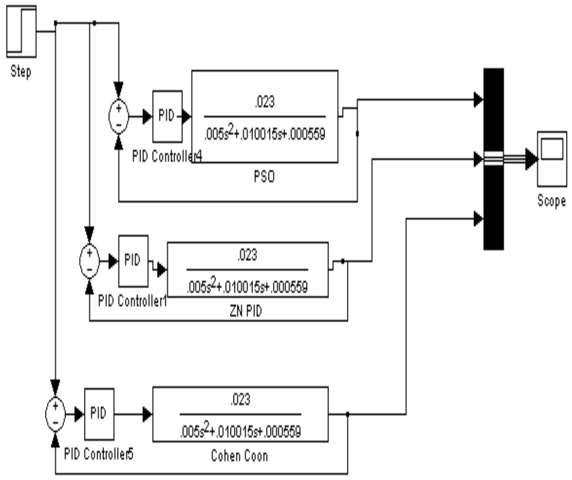


Fig.8 Simulink model of various tuning methods

The parameters used to describe the electrical and electromechanical systems are given below.

Table 2 Parameters of DC Motor

Parameter	Values & Unit
R	1Ω
K_b	.023 Kg-m/A
K_t	.023 Vs/rad
L	.0.5 H
J_m	.01 Kgms²/rad
B_m	.00003 Kgms/rad

V. RESULTS AND DISCUSSION

The Simulink model in Fig. 7& 8 was simulated and the plots for various tuning method were observed. Fig. 9 and Fig. 10 shows the Speed versus Time plot for conventional and bio inspired optimization method (PSO) respectively .

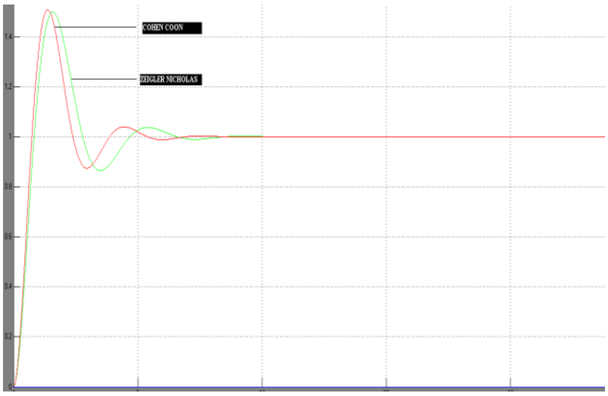


Fig. 9 Speed versus Time plot with reference speed for PID tuned with Zeigler Nicholas & Cohen Coon

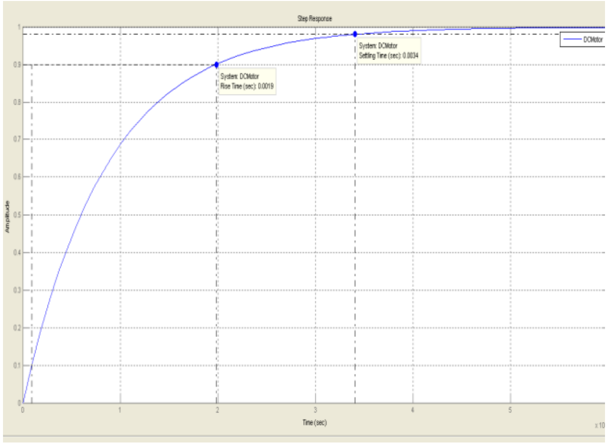


Fig. 10 Speed versus Time plot with reference speed for PID tuned with Particle swarm optimization

From the above two result it is clear that bio inspired optimization method is far better than the conventional tuning method. Their comparison is shown in figure 11 and detailed comparative analysis considering all the parameter is given in Table 4.

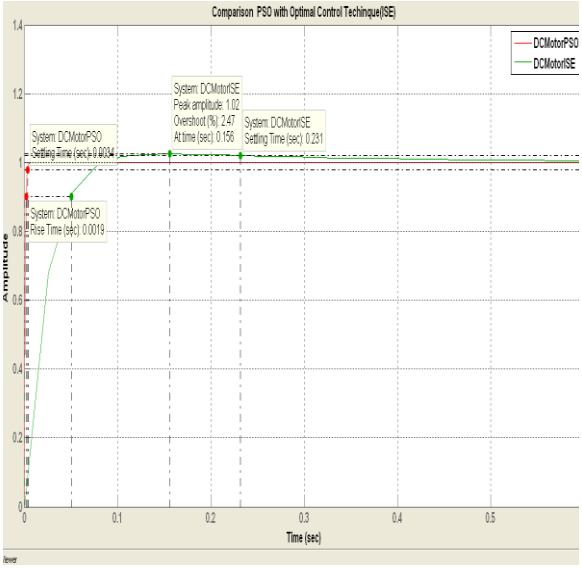
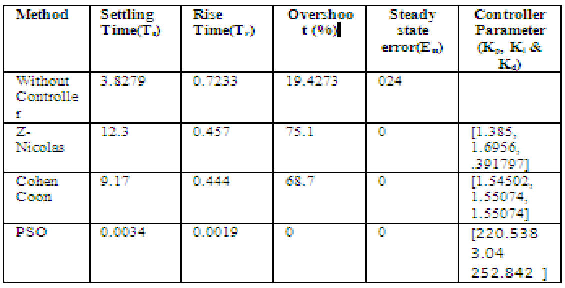


Fig. 11 Speed versus Time plot with reference speed for PID tuned with ZN, CC, and PSO

Table:3 Comparative analysis of various tuning methods



Method	Settling Time(T_s)	Rise Time(T_r)	Overshoot (%)	Steady state error(E_{ss})	Controller Parameter (K_p, K_i & K_d)
Without Controller	3.8279	0.7233	19.4273	024	
Z-Nicolas	12.3	0.457	75.1	0	[1.385, 1.6956, .391797]
Cohen Coon	9.17	0.444	68.7	0	[1.54502, 1.55074, 1.55074]
PSO	0.0034	0.0019	0	0	[220.538 3.04 252.842]

It can be seen from the above comparison table that while using the bio-inspired technique (Particle Swarm Optimization) the overshoots obtained is zero as compared to the case when the PID Controller is was tuned via conventional methods. The settling time is also lesser in case of the Particle Swarm Optimization, also the rise time is reduced. The Particle Swarm Optimization PID controller tends to approach the reference speed faster and has, comparatively, a zero overshoot. It can be observed from Fig 12 th[5] Benjamin C. Kuo, FaridGolnaraghi, 2009. Automatic Control Systems, 9th ed., John Wiley & Sonsat the Conventional PID controller have overshoot from the reference speed and attain a steady state with larger settling time

VI. CONCLUSION

Performance comparison of different controllers has been reviewed and it is found that Particle Swarm Optimization is very good performers when time domain analysis is considered, but their performance for frequency domain and robustness analysis is not very good. So this can be taken as a research work in future so that PSO gives optimum performance in all three fields of time domain, frequency domain and robustness analysis. The conventional controllers however are not recommended for higher order and complex systems as they can cause the system to become unstable. Hence, a heuristic approach is required for choice of the controller parameters which can be provided with the help of Bio-inspired optimization methods i.eParticle Swarm Optimization, where we can define variables in a subjective way.

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GeetaKumariBelong to Bihar Received her Bachelor of Technology degree from S.H.I.A.T.S University, Allahabad in 2012. She is pursuing her M.Tech in Electrical Engg. (Power System) from SHIATS, Allahabad, UP-India.
Email: geeta.roy020@gmail.com

AUTHOR'SPROFIE

Dr. Surya Prakash Belong to Allahabad, Received his Bachelor of Engineering degree from the institute of Engineers (India) in 2003, He obtained his M.Tech in Electrical Engg. (Power System) from KNIT Sultanpur, UP-India.in 2009 and Ph. D.From SHIATS University, Allahabad in 2013. Presently he is working as Asst. Prof. in Electrical Engg. Dept. SSET, SHIATS (Formally Allahabad Agriculture Institute, Allahabad-India).His field of interest includes power system operation & control, Power Electronics, Artificial Intelligent control.
Email: sprakashgiri0571@yahoo.com

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