Utilizing Adaptive Tabu Search Technique Based Tuning PID Controller for Optimal Speed Control Single Phase Induction Motor

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Abstract

The PID algorithm is the most popular controller used within the process industries. Robust easily understood algorithm could provide excellent control performance despite of the varied dynamic characteristic of process plant. However, the tuning of the PID controller parameters are not easy and does not give the optimal required response, especially with non-linear system. In the last years emerged several new intelligent optimization technique like, Adaptive Tabu search (ATS), Particle Swarm Optimization (PSO) techniques to get better control of the speed. This Paper deals with the speed control of single Phase Induction Motor with closed loop PID controller using (ATS) as intelligent optimization technique . The system is simulated using Matlab/Simulink GUI environment and the results are discusses.

The Ziegler– Nichols methods for tuning PID controller is represent as a point of comparison. The intelligent optimization technique ATS is propos to tune the PID controller parameters to get optimal results of the closed loop of PID - ATS Controller. The Simulation results show the effectiveness of the propose method, which has get number of advantages.

Keywords: Adaptive Tabu search, single-phase induction motor, PID Controller

استخدام تقنية البحث التكيفي (Tabu) كأساس لإيجاد خوارزمية المسيطر (PID) للوصول الى أفضل سيطرة لسرعة المحرك الحثي احادي الطور

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الخلاصة

ان خوارزمية نظام السيطرة (PID) الأكثر شعبية يستعمل ضمن العمليات الصناعية. هي خوارزمية سهلة الفهم ومتينة والتي يمكن ان تزود أداء سيطرة ممتازة ولكن عملية توليف معاملات المسيطر(PID) ليست سهلة ولا تعطي الاستجابة المثلى المطلوبة، خصوصا مع الأنظمة اللاخطية. في السنوات الأخيرة ظهرت عدة تقنيات ذكية جديدة لتحقيق الاستجابة المثلى، من هذه التقنيات تقنية البحث التكيفي الاتجاهي (Adaptive Tabu Search).

يعالج هذا البحث نموذج رياضي يحاكي السيطرة سرعة محرك احادي الطور مع نظام السيطرة (PID) وان توليف المسيطر تمت باستخدام تقنيتان الأولى باستخدام التقنية الذكية (Adaptive Tabu Search) والثانية باستخدام التقنيات الاعتيادية وهي (Ziegler-Nichols Methods) وتم مقارنة النتائج بينهما.

تبين من النتائج بأن التقنية الأولى لها استجابة ممتازة مقارنة مع التقنية الثانية.

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1. Introduction

Control System Design and Analysis Technologies are widely suppress and very useful to applied in real-time development. Some can solved by hardware technology and some by the advanced software.

Proportional-Integral-Derivative (PID) controller is one of the earliest control technique that use widely in industry because of its easy implementation, robust performance and simple of physical principle of parameters .For achieving appropriate closed-loop performance, the three parameters of the PID controller must tuned. [1]

Tuning methods of PID parameters are classify as conventional and intelligent methods.

Conventional methods such as Ziegler-Nichols and simplex method are hard to determine optimal PID controller parameters and usually are not give good tuning. [2]

Recently, intelligent approaches such as genetic algorithm (GA), particle swarm optimization (PSO) and Adoptive Tabu Search (ATS) are propose for optimization of PID parameters.

The ATS technique can generate a high quality solution within a shorter calculation time and have a stable convergence characteristic than other methods. The ATS algorithm is apply to search best PID controller parameters. ATS is characterized as a simple concept, easy to implement, and computationally efficient. Unlike the other heuristic techniques, ATS has a flexible and well-balanced mechanism to enhance the global and local exploration abilities. [3]

In this study Adaptive Tabu Search (ATS) algorithm is used to tune the PID controller parameters to control the speed of single phase induction motor as a modern intelligent optimization algorithm .

2. Control the speed of Single-phase induction motor

2.1. Construction of motor [2]

Fig.1 shows the construction of the single-phase induction motor includes a stator where the primary winding is wounds and a basket-shaped, solid aluminum die cast rotor. The rotor is low-cost because the structure is simple and does not use a magnet.

2.2. Methods of speed control [4]

The basic methods of speed control of induction motor are:

1- Variable terminal voltage control.
2- Variable frequency control.
3- Rotor resistance control.
4- Injecting voltage in the rotor circuit.

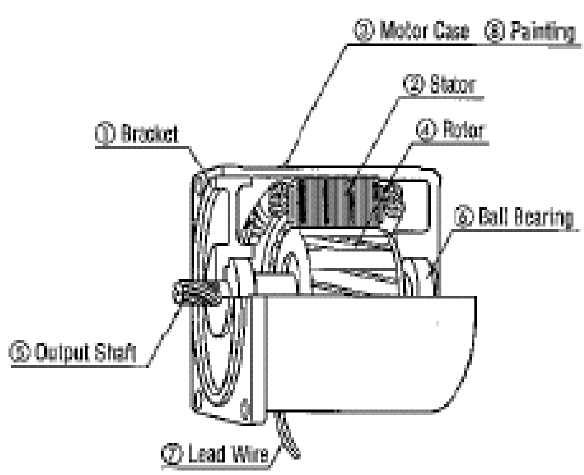

Fig. (1) Construction of the single-phase induction motors

In general, the synchronous speed is directly proportional to the supply frequency. Hence, the motor speed can controlled below and above the normal full-load speed by changing the supply frequency.

2.3. Control Circuit Unit (PWM Control) [5]

The control circuit unit contain as:

1- Invertor
2- Sinusoidal PWM Setting
3- Comparator
4- Sine Wave Function and Triangular Wave

The block diagram of control circuit unit shown in figure (2)

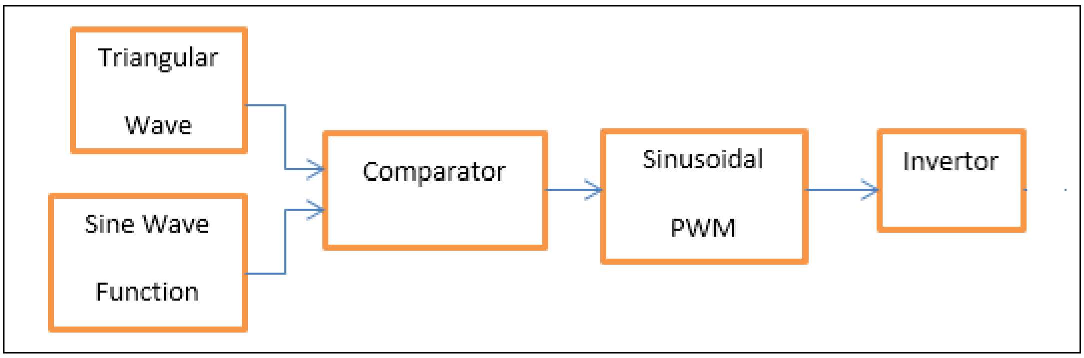

Fig.2 Block diagram of Control Circuit Unit

In order to control the speed of single-phase induction motor [1], Single-Phase Bridge Inverter is use with PWM control. The ON/Off time is control so that the fundamental voltage applied to the motor become sine-wave shape by comparing the triangular wave called a carrier signal with the sine-wave shaped signal waveform. This method is call PWM control. As shown in Fig. 3.

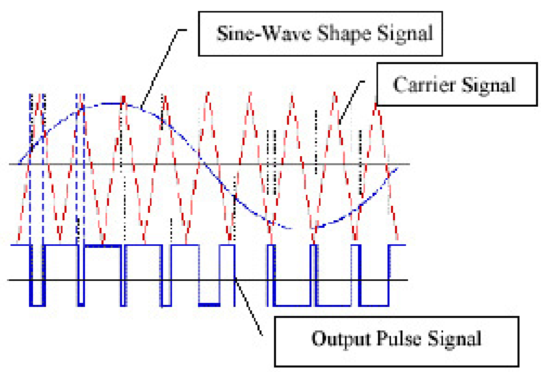

Fig. 3 PWM Signal Synthesis

2.4. Speed control methods [6]

The Single-Phase Bridge Inverter controls the speed of the induction motor by changing the output voltage and frequency of the applied voltage to the motor. The inverter unit changes the frequency (f) by changing the ON/OFF cycle of the four switching elements, and the rotational speed (N) of the motor changes in proportion to the expression in formula (1).

$$N = \frac{120 * f * (1-S)}{P} \qquad \text{.......................................} \ (1)$$

N: Rotational speed [r/min]

f : Frequency 〔Hz〕

P: Number of poles of a motor, S: Slip

The speed control method of the invertor unit is divide into the two types: open-loop control that simply changes the speed of the motor and closed-loop control, which controls the speed of the motor to desired speed and reduces the speed variation with load changes of the motor.

1) Open-loop control

Fig.4 shows the block diagram of the open-loop control.

This method is use to change the output voltage and frequency of the inverter according to setting speed. This method is suitable for changing speed. Simply when the speed regulation with varying loads is not so much of a concern.

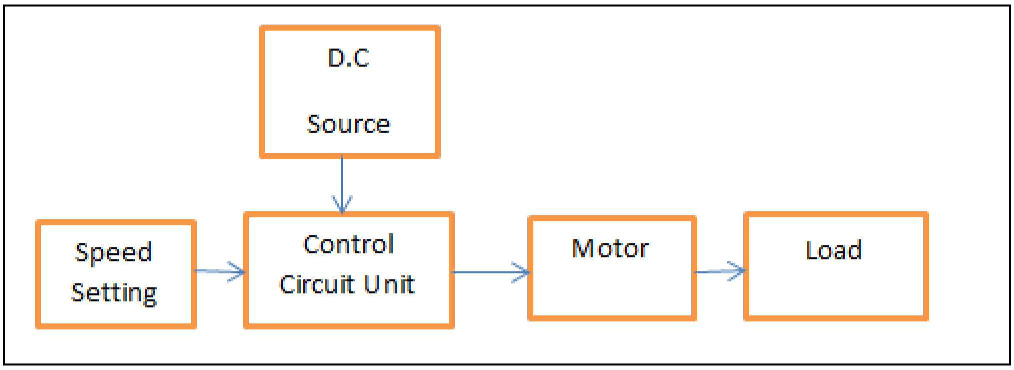

Fig. 4 Block diagram of open-loop control

2) Closed-loop control

Fig. 5 shows the block diagram of the closed-loop control.

The parameters of the PID Controller as optimal results will find by using PID-ATS technique as intelligent optimization.

The generated torque **T** of the motor is show by the formula (2). From this relation, it can see that the torque will be constant by making the ratio of voltage **V** to frequency **f** **(V\f)** constant.

$$T = \frac{K*I*V}{f} \qquad \text{.. (2)}$$

T: Torque [N.m],

V: motor applied voltage [V]

I: Motor current [A]

f: Frequency [Hz]

K: Constant

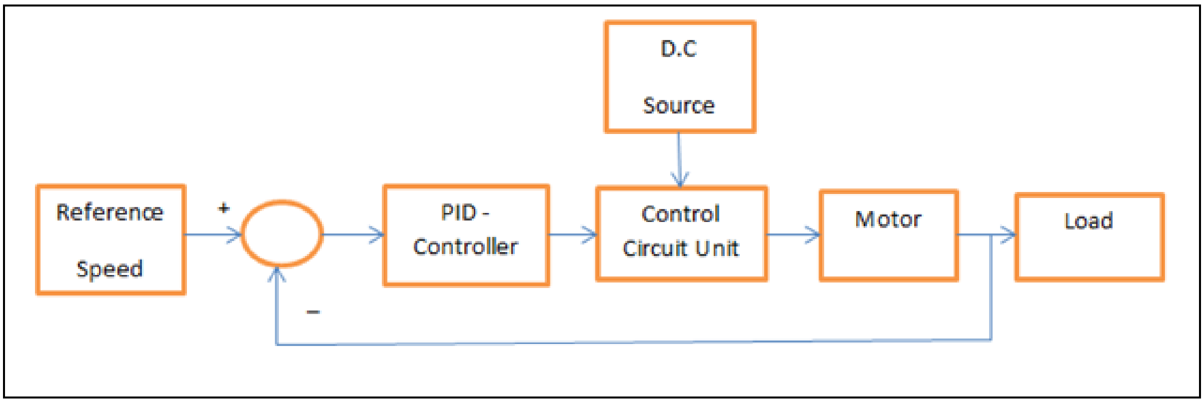

Fig. 5 Block diagram of closed-loop control

3. Realization of a PID-ATS Controller Tuning Optimal Parameters

The general equation of PID controller is

$$\mathbf{U(t) = K_p * e(t) + \frac{1}{T_i}\int e(t)\,dt + T_d \frac{de(t)}{dt}} \quad \dots\dots\dots\dots\dots\dots (3)$$

Where $\mathbf{K_p}$ = proportional gain; $\mathbf{T_i}$ = time integral; $\mathbf{T_d}$ = time derivative.

The variable $\mathbf{e(t)}$ represents the error, which is the difference between the desired output and the actual output. This error signal fed to the PID controller, which computes both the derivative and integral of this error signal.

3.1 Fitness Function (FF) [7] [8]

The most common performance criteria of the fitness function are integrated absolute error (IAE) , the Integrated of Time weight square Error (ITSE) and integrated of Square Error (ISE) that can be evaluated analytically in frequency domain [1] .
In the paper the IAE is use as fitness function (FF) for evaluating the PID controller performance, the performance criterion formula for IAE is as follow:

$$\mathbf{IAE = \int_0^{\infty} |r(t) - y(t)|dt = \int_0^{\infty} |e(t)|\,dt} \quad \dots\dots\dots\dots\dots (4)$$

A set of tuning parameters, K_p K_i, K_d can yield a tuning step response that will result in performance criteria minimization the FF in the time domain.
These performance criteria includes the over shoot, rise time, settling time, and steady state error.

3.2 Scheduling ATS for PID Controller Parameters [9]

An ATS Algorithms used to find the optimal parameters of the PID controller to control the speed of single-phase induction motor. The structure of the PID-ATS controller is show in fig. 6 .

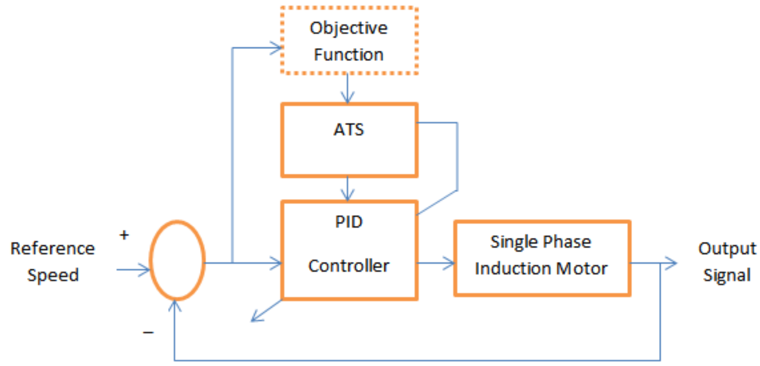

Fig. 6 Block diagram of PID Controller with ATS Algorithm

4. Adaptive Tabu Search [3]:

The adaptive tabu search (ATS) is the modified version of the tabu search (TS). Based on iterative neighborhood search approach, the ATS was launched in 2004 [12], The ATS search process begins the search with some random initial solutions belonging to a neighborhood search space. All solutions in neighborhood search space will evaluated via the objective function. The solution giving the minimum objective cost is set as a new starting point of next search round and kept in the tabu list (TL). Fig. 7 illustrates some movements of the ATS.

The ATS algorithm is summarize systematic as follows.

Step 1. Initialize a search space (Ω), TL = ▫, search radius (R), count, and maximum radius (MAXR).
Step 2. Randomly select an initial solution S_0 from a certain search space Ω. Let S_0 be a current local minimum.
Step 3. Randomly generate N solutions around S_0 within a search radius R. Store the N solutions, called neighborhood, in a set X.
Step 4. Evaluate the objective value of each member in X via objective functions. Set S_1 as a member giving the minimum cost.
Step 5. If f (S_1) < f (S_0), put S_0 into the TL and set S_0=S_1, otherwise, store S_1 in the TL instead.
Step 6. Activate the backtracking (BT) mechanism, when a local entrapment occurs.
Step 7. If the termination criteria (TC): count= countmax or desired specification are met, then stop the search process. S_0 Is the best solution, otherwise go to Step 8.
Step 8. Invoke to Step 2.the adaptive radius (AR) mechanism, once the search approaches the local or the global solution to refine searching accuracy.
Step 9. Update count= count+1, and go back
The diagram in Fig. 7 reveals the search process of the ATS algorithm.
Fig. 8 show the flow chart of PID-ATS Controller.

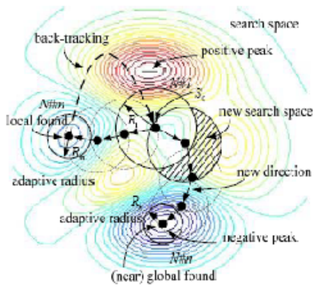

Fig. 7 some movements of ATS

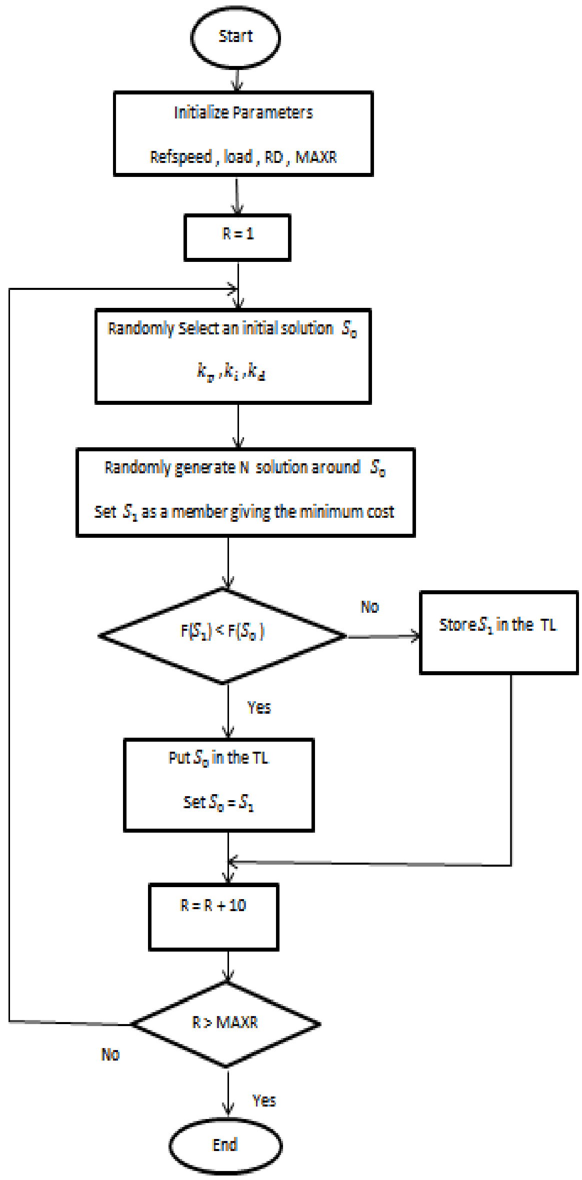

Fig. 8 flow chart of PID-ATS controller

5. The Ziegler-Nichols ods for tuning PID Controllers [2]

The selection of the PID controller parameters $\mathbf{K_p}$, $\mathbf{T_i}$ and $\mathbf{T_d}$ can be obtained by using the classical control system design techniques like Ziegler and Nichols methods. It has two empirical methods for obtaining the controller parameters, The Process Reaction Method and The Continuous Cycling Method.

The process Reaction Method : It is based on the assumption that the open loop step response of most process control systems has an S-shape , called the process reaction curve , as shown in Figure (9) . The process reaction curve may be approximated to a time delay D and first order system of maximum tangential slope R.

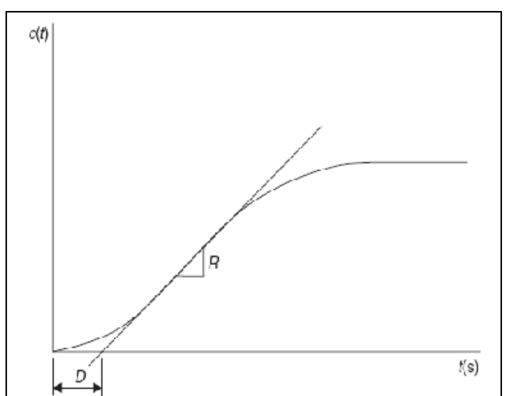

Fig. 9 Process reaction curve

The process Reaction Method assumes that the optimum response for the closed loop system occurs when the closed loop-damping ratio has a value of 0.21. The controller parameters , as a function of R and D , to produce this response , are given in Table 1 .

.

Table (1) Ziegler – Nichols PID parameters using the Process Reaction Method

Controller type	K_p	T_i	T_d
P	$1/RD$	–	–
PI	$0.9/RD$	$D/0.3$	–
PID	$1.2/RD$	$2D$	$0.5D$

In this paper, we chose different value of (D, R) in order to get best value of PID parameters by using trial and error method

6. Simulation Results

6.1 Implementing ATS Tuning for PID controller:

The MATLAB Simulation to control the speed of single phase induction motor using the Single-Phase Bridge Inverter and PWM generator at reference speed shown in figure (10) , according to trials , the adaptive tabu search algorithm search the optimal speed in each examined iteration . Table (2) shows the ATS parameters' which used to verify the performance of PID-ATS controller parameters .

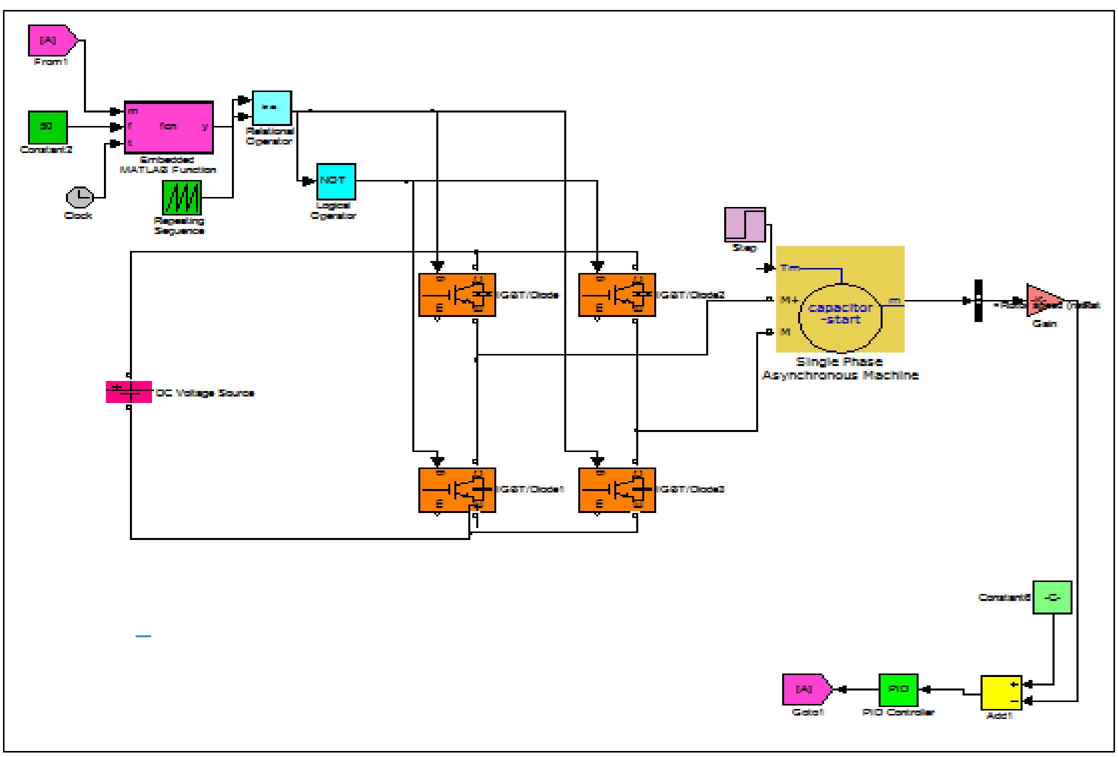

Fig. (10) MATLAB Simulation to control the speed of single-phase induction motor

Table (2) Parameters of ATS algorithm

Number of neighborhood (N)	30
Population size	3
Search radius (R)	10

The simulation results are obtained for one second range time , The speed response of PID controller tuning parameter using ATS is shown in figure (11) ,

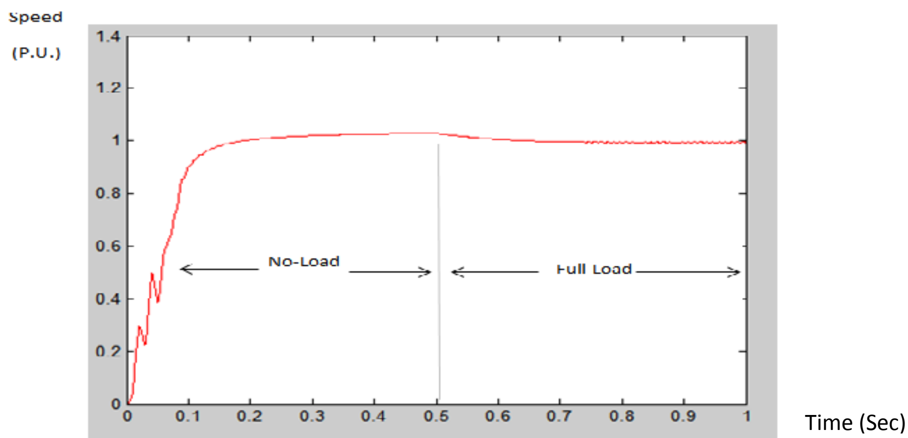

Fig. (11) Speed response of PID Controller tuning parameter using ATS Strategy

The Output of the performance system under no-load and full-load conditions as follow:

- Rise time = 0.099 sec
- Maximum overshoot = 0.01 p.u.
- Settling time = 0.125 Sec
- Steady stat error = 0
-

6.2 The Ziegler-Nichols Tuning for PID controller:

We chose different value of (D, R) in order to get best value of PID parameters by using trial and error method as shown in Tables (3), (4) and fingers (12), (13)

7. Comparison and discussion between ATS tuning PID and Ziegler – Nichols tuning for the parameters of PID controller:

A comparison is made between PID-ATS controller and Ziegler-Nichols controller to approach the effectiveness of the control , the performance comparison is shown in table (3) and table (4)

Table (3) The set of Tuning parameters, K_p, K_i, K_d comparison between PID-ATS controller and Ziegler-Nichols controller at No-load and Full-load

Results	No-load		Full-load	
	Zieg.-Nich. Controller	PID-ATS Controller	Zieg.-Nich. Controller	PID-ATS Controller
Proportional gain (K_p)	11.4286	33.2578	31.5789	27.2709
Integral gain (K_i)	5.7143	6.5405	39.4737	11.7993
Derivative gain (K_d)	0.0571	0.0097	0.0632	0.0211

Table (4) Performance of PID-ATS controller and Ziegler-Nichols controller

Results	No-load		Full-load	
	Zieg.-Nich. Controller	PID-ATS Controller	Zieg.-Nich. Controller	PID-ATS Controller
Rise time (sec.)	0.237	0.098	0.097	0.106
Max. Overshot	0.02	0.01	0.03	0
Settling time (Sec.)	0.335	0.124	0.106	0.135
Steady state error (%)	1.2 %	1 %	2 %	1 %

The speed response of the PID-ATS Controller comparing with the speed response of the Ziegler-Nichols Controller at no-load and full load are shown in figure (12) .

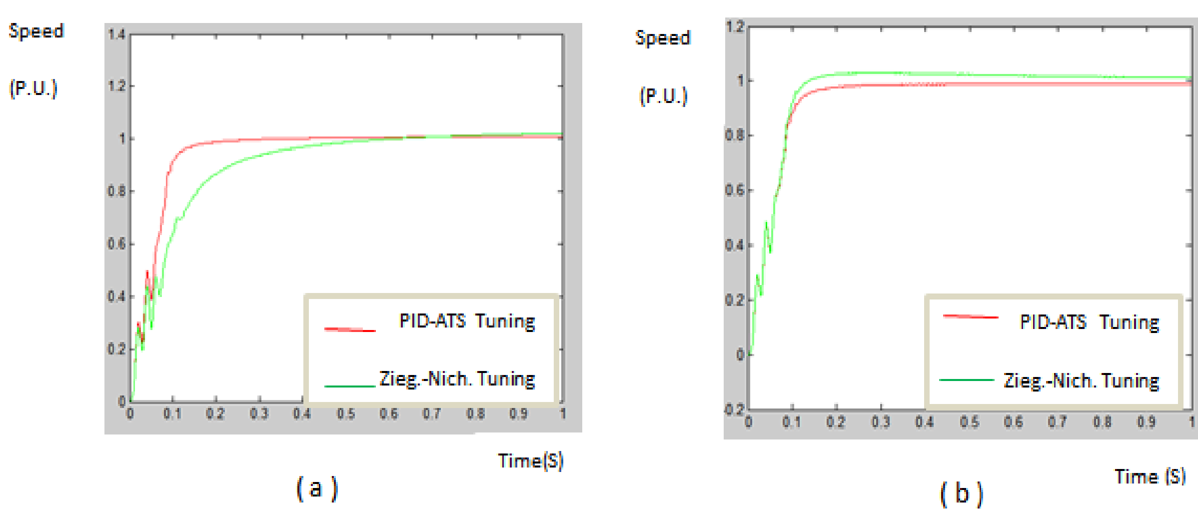

Fig. (12) Comparing performance of PID-ATS controller and Ziegler-Nichols Controllers at

(a) Per-unit No-load , (b) per-unit full-load

The speed response of the PID-ATS controller and Ziegler-Nichols Controller at suddenly change the load from No-load to full-load as shown in figure (13).

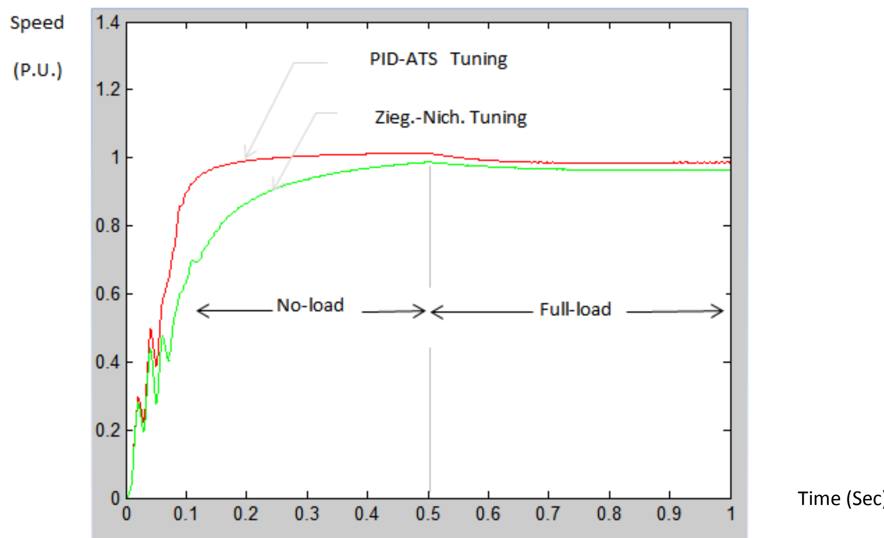

Fig. (13) Speed response of the ATS and Ziegler-Nichols PID Controllers at suddenly change the load from No-load to full-load

From the above figures (12 & 13), we can see that the output takes less time to stabilize, which can observed from simulation results. However, PID-ATS controller gave better results than Ziegler-Nichols Controller by reach the reference speed (per unit speed) very quickly.

8. Conclusions

In this paper, two controller, the PID- ATS and Ziegler-Nichols PID controllers control the speed of a Single-phase induction motor, then obtained through MATLAB simulation the performance of the system under no-load and full-load conditions, the comparison between them is made, there are:

- The controller (PID-ATS) shows that the response speed of Single-phase induction motor an efficient for the optimal PID controller because can be improve the dynamic performance of the system.
- By comparison, PID-ATS controller give better results than Ziegler-Nichols controller by reach the reference speed or per unit speed the mean that it is much more robust finding optimal control parameters.
- The ATS-Tuning PID Controller give better results because it has satisfactory performance and very robust (no overshoot, minimal rise time, minimal settling time, and steady state error is minimum).
- The advantage of using ATS Tuning PID minimized the error when we calculate the step response of the system because the iterations continuously run until the error minimized.

9. APPENDIX

Table (5)

Single phase induction motor parameters

Power (W)	0.25 × 746	**Voltage (V)**	220
Main winding stator resistance (R_{1m}) (Ω)	2.02	**Auxiliary winding stator resistance (R_{1a}) (Ω)**	7.14
Main winding stator inductance (L_{1m}) (H)	7.4 ^-3	**Auxiliary winding stator inductance (L_{1a}) (H)**	8.5 ^-3
Main winding mutual inductance (Lm)(H)	0.1772	Turn ratio **a=Na/Nm**	1.18
Main winding rotor resistance (r_2`) (Ω)	4.12	**Pair poles (P)**	2
Main winding rotor inductance (L_2`) (H)	5.6 ^-3	**Inertia (Jm) (kg.m^2)**	0.0146

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The work was carried out at the college of Engineering. University of Mosul