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Optimal Speed Control Single Phase Induction Motor using Fuzzy Controller Tuning by Adaptive Tabu Search Technique

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***Abstract*—in this article, a comparative study was down for nonlinear drive control of single-phase induction motor. Two types of controllers, namely adaptive tabu search based tuning of fuzzy controller (Fuzzy-ATS) and Ziegler– Nichols methods for tuning PID controller have proposed to control of nonlinear drive. The main objective is obtain the better performance of system in stability , minimum settling time and minimum overshoot in system response under the various conditions like change in load , change in speed and change in both load and speed of the motor .**

The Ziegler– Nichols methods for tuning PID controller has represented as a point comparison. The intelligent optimization technique ATS has proposed to tune the fuzzy controller parameters to get the optimal results of the close loop of Fuzzy - ATS Controllers.

The system is simulate using Matlab/Simulink GUI environment and the results have discussed. From the discussion of result, it has been found that Fuzzy - ATS Controllers perform well in providing better settling time and better control of the speed of single phase induction motor.

Index Terms—**Adaptive Tabu search, single phase induction motor, Fuzzy Controller, Optimal Control**

I. INTRODUCTION

Control System Design and Analysis Technologies are widely suppress and very useful to be applied in real-time development. Some has be solved by hardware technology and by the advance used of software.

Proportional-Integral-Derivative (PID) controller is one of the earliest control techniques that is stall used widely in industrial because of its easy implementation robust performance and being.

Simple of physical principle of parameters .For achieving appropriate closed-loop performance, three parameters of the PID controller must tuned.

Tuning methods of PID parameters are classified as traditional and intelligent methods.

Conventional methods such as Ziegler-Nichols and simplex method are hard to determined optimal PID parameters and usually are not cause good tuning.

Recently, intelligent approaches such as genetic algorithm (GA), particle swarm optimization (PSO) and Adoptive Tabu Search (ATS) have been proposed for PID optimization.

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 has applied to search a best PID control 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.

In this study Adoptive 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 .

II. CONTROL OF SINGLE-PHASE INDUCTION MOTOR

A. Construction of motor

The construction of the single-phase induction motors 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.

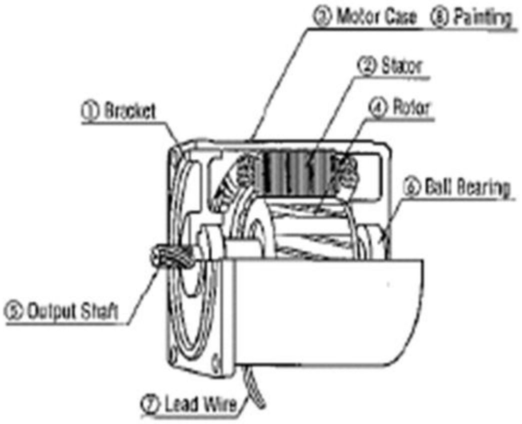

Fig. (1) Construction of the single-phase induction motors

B. Principle of speed control

The basic principles of employed in power semiconductor controlled induction motor drives. These method are

Variable terminal voltage control.

Variable frequency control.

Rotor resistance control.

Injecting voltage in the rotor circuit.

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

C. Inverter Speed Control Unit

In order to control the speed of single-phase induction motor, the Single-Phase Bridge Inverter has used with PWM control. The ON/Off time has controlled so that the average voltage applied to the motor becomes a sine-wave shape by comparing the triangular wave called a carrier signal with the sine-wave shaped signal waveform. This method has called PWM control. As shown in Fig. 2.

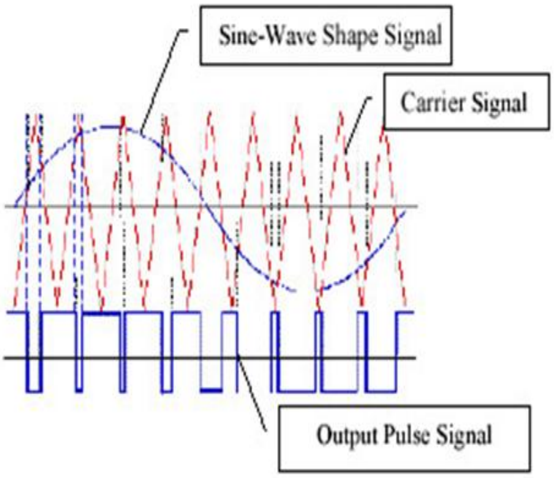

Fig. 2 Duty control of ON/OFF

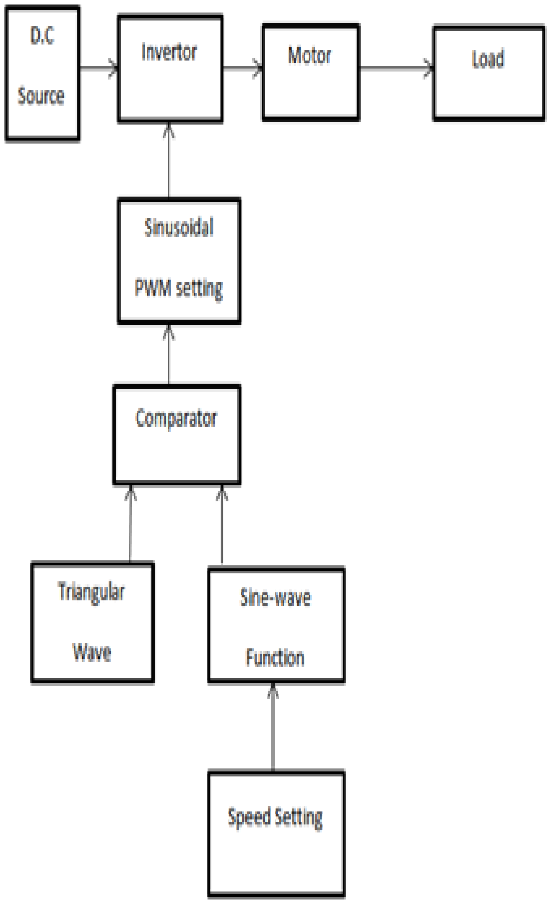

Fig. 3 Block diagram of open-loop control

D. Speed control method

The Single-Phase Bridge Inverter control the speed of the induction motor by changing the frequency (f) 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).

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

N: Rotational speed [r/min]
F: Frequency 〔Hz〕
P: Number of poles of a motor,
S: Slip

The speed control method of our inverter unit has divided into the two types: open-loop control that simply changes the speed and closed-loop control that control the speed of the motor to desire (reference) speed and reduces the speed variation with load changes of the motor.

1. Open-loop control

Fig.3 shows a configuration of the open-loop control in a block diagram. This method is use to change the output voltage and frequency of the inverter according to set speed. This method is suitable for changing speed and can obtain high speeds. Simply when speed regulation with varying loads will not so much of a concern.

2. Closed-loop control

Fig. 4 shows the block diagram configuration of the closed-loop control system using the inverter as control speed unit.

It has be seen that, the parameters of the Fuzzy Controller as optimal results are find by using Fuzzy -ATS technique as intelligent optimization.

The generated torque T of the motor has shown by the formula (2). From this relation, it has said that the torque is constant by making V/f (the ratio of voltage V to frequency f) constant.

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

T: Torque [N.m],
V: Power supply voltage [V]
I: Motor current [A]
F: Frequency [Hz]
K: Constant

However, the lower the speed is, the motor difficult, it is to keep constant input impedance of the induction motor with the change in f. Therefore, to obtain a torque that is constant from low speed to high speed it is necessary to adjust the V/f ratio at low speed in accordance to the characteristics of the motor.

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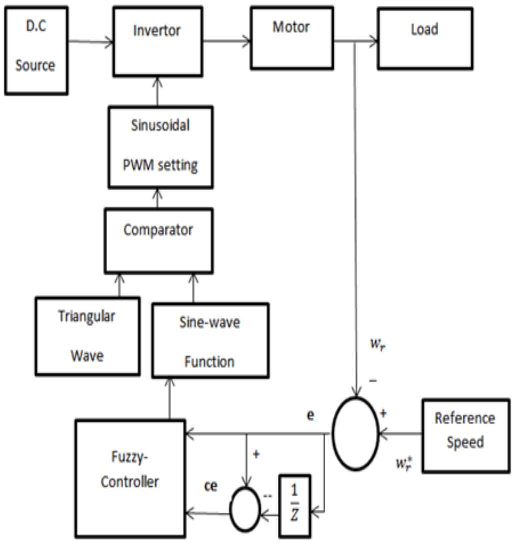


Fig. 4 Block diagram of closed-loop control

III. REALIZATION OF A FUZZY-ATS CONTROLLER TUNING OPTIMAL PARAMETERS

A. Design of Fuzzy Logic Controller

Fig. (4) show block diagram of close-loop control system using fuzzy logic controller (FLC) to control the speed of single-phase induction motor.

Here the first input to the (FLC) is the speed error (e) and second is the change in speed error (ce) at sampling time (t_s). The two input variables e (t_s) and ce (t_s) are calculated at every sampling time as:

e (t_s) = $w_r^*(t_s) - w_r(t_s)$ ……… (3)

ce (t_s) = e (t_s) – e(t_s – 1) ………..(4)

Where ce denotes the change of error e, $w_r^*(t_s)$ is the reference rotor speed, $w_r(t_s)$ is the actual speed, e(t_s – 1) is the value of error at previous sampling time . The output variable is the change in speed Δw which is integrated to get the reference speed as shown in the equation

$w_r(t_s) = w_r(t_s - 1) + \Delta w$ ………. (5)

The fuzzy logic controller consists of four blocks, Fuzzification, inference, knowledge base and Defuzzification.

1. Fuzzification :

   In this stage the crisp variables of input e (t_s) andce (t_s)are converted into fuzzy variables. The fuzzification maps the error and change in error to linguistic labels of fuzzy sets. Membership function is associated to each label with triangular shape that consists of two inputs and one output. The proposes controller uses following linguistic labels NB,NM,NS,ZE,PS,PM,PB. Each of the inputs and output contain membership function with all these seven linguistics.

2. Knowledge base and inference stage :

   Knowledge base involves defining the rules represented as IF-THEN rules statements governing the relationship between input and output variables in terms of membership function. In this stage the input variables e (t_s) and ce (t_s) are processed by the inference mechanism that executes 7*7 rules represented in rule table shown below. Considering the first rule, it will represent as IF change in speed error is NB and change in speed is NB, THEN the output will be NB Here Madman's algorithm for inference mechanism used.

3. Defuzzification :

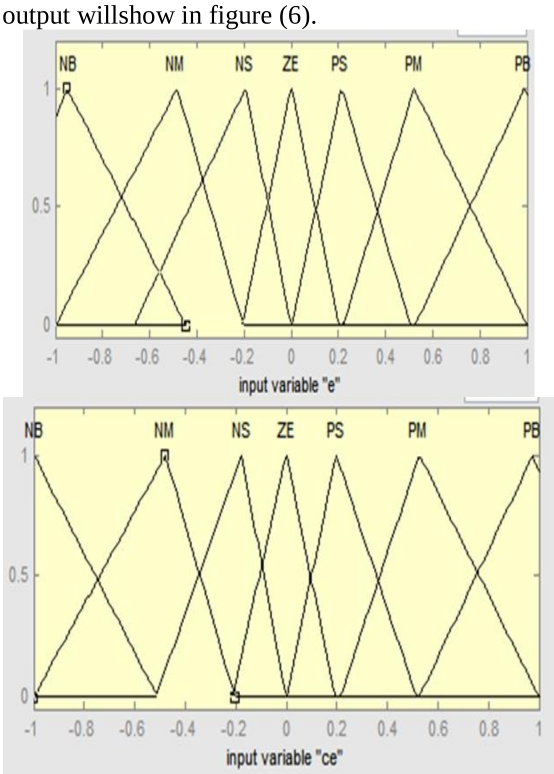
   This stage introduces different methods that can be used to produce fuzzy set value for the output fuzzy variable Δw.

   Here the center of gravity or centroids method is used to calculate the final fuzzy value Δw (t_s). Defuzzification using COA method means that crisp output of $\Delta w^*(t_s)$ is obtained by using Centre of gravity, in which the crisp output Δw (t_s) variable is taken to be the geometric Centre of the output fuzzy variables value μ_{out}(Δw) area, where μ_{out}(Δw) is formed by taking the union of all the contributions of rules with the degree of fulfillment greater than zero. Then the COA expression with discretized universe of discourse can written as

$$\Delta w = \frac{\sum_{i=1}^{n} \Delta w_i \cdot \mu_{out}(w_i)}{\sum_{i=1}^{n} \mu_{out}(\Delta w_i)} \quad \ldots \ldots (6)$$

The Membership Function of Fuzzy variablesμ_e, μ_{ce} , and μ_w are shown in figure (5), and the Fuzzy Controller Rule Base is shown in table (1) .

The Rules view and Surface view of fuzzy controller output willshow in figure (6).



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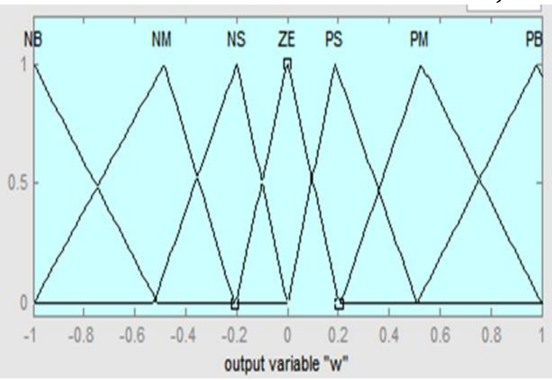
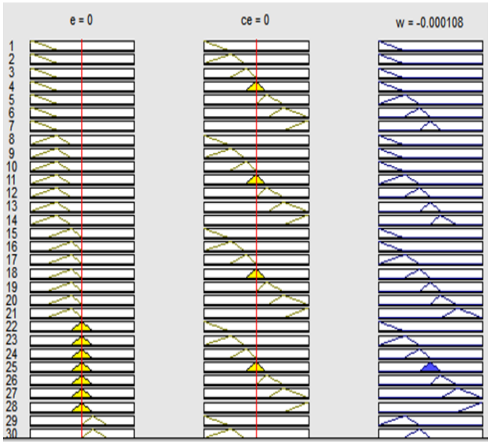


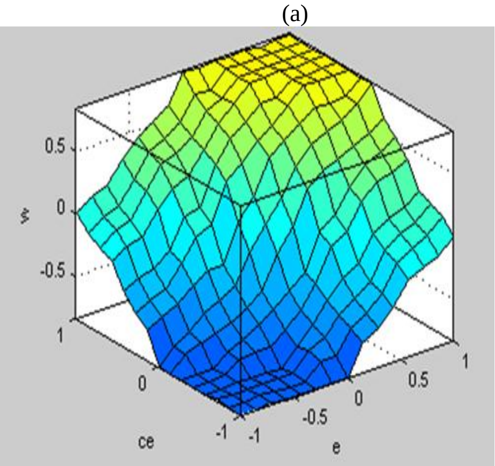
Fig. 5 Membership Function of Fuzzy Variables μ_e, μ_{ce}, and μ_w

Table (1) Fuzzy Controller Rule Base

ce(pu) \ e(pu)	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
ZE	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB



(a)



(b)

Fig. 6 (a) Rules view of fuzzy controller output (b) Surface view of fuzzy controller output

B. Fitness Function (FF)

The most common performance criteria 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 .

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:

$$\mathbf{IAE} = \int_0^\infty |\mathbf{r(t) - y(t)dt}| = \int_0^\infty |\mathbf{e(t)dt}| \quad .. \quad (7)$$

A set of good control parameters K_e, K_{ce}, K_w can yield a good step response that are result in performance criteria minimization the FF in the time domain.
These performance criteria are include the over shoot, rise time, settling time, and steady state error.

C. Scheduling ATS for Fuzzy Controller Parameters

An ATS Algorithms are use to find the optimal parameters of the fuzzy controller to control the speed of single-phase induction motor. The structure of the fuzzy controller with ATS algorithm will show in fig. 5

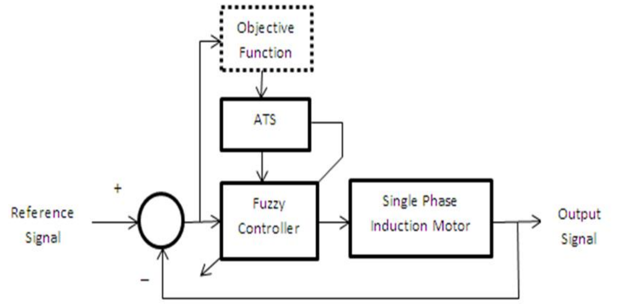


Fig. 5 Block diagram of proposed PID Controller with ATS Algorithm

IV. ADAPTIVE TABU SEARCH

The adaptive tabu search or ATS is the modified version of the TS. Based on iterative neighborhood search approach, the ATS was launch in 2004; 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. 6 illustrates some movements of the ATS.

The ATS algorithm will summarized 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 from a certain search space Ω. Let S be a current local minimum.

Step 3. Randomly generate Nsolutions around within a search radius R. Store the Nsolutions, called neighborhood, in a set X.

Step 4. Evaluate the objective value of each member in X via objective functions. Set as a member giving the minimum cost.

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Step 5. If f( ) <f( ), put into the TL and set .= ., otherwise, store . in the TL instead.

Step 6. Activate the 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. is the best solution, otherwise go to Step 8.

Step 8. Invoke 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 to Step 2.

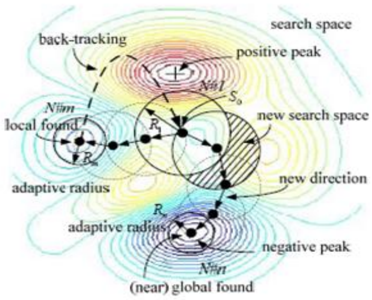

Fig. 6 some movements of ATS

The diagram in Fig. 6 reveals the search process of the ATS algorithm.

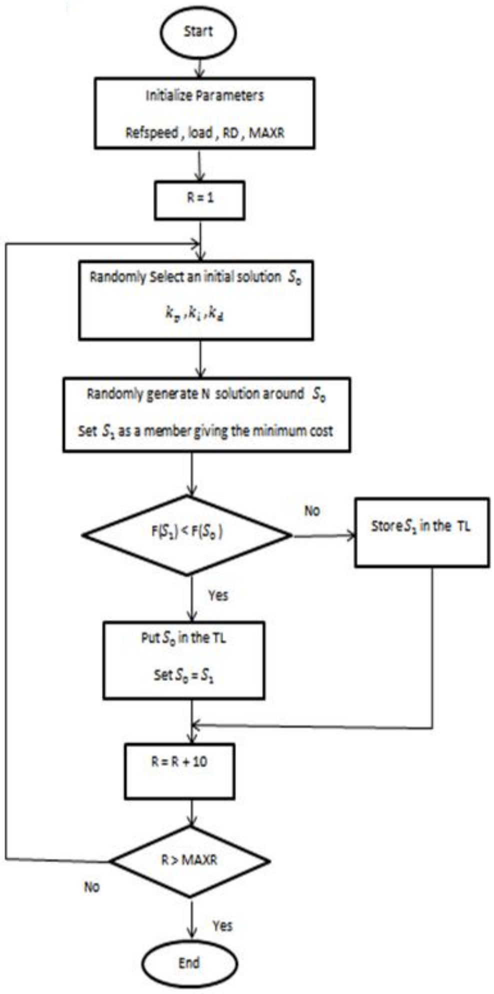

Fig. 7 flow diagram of Fuzzy-ATS controller

V. THE ZIEGLER-NICHOLS METHODS FOR TUNING PID CONTROLLERS

The selection of the PID controller parameters K1 , Ti and Td can be obtained by using the classical control system design techniques like Ziegler and Nichols methods. It have two empirical methods for obtaining the control parameters:

- The Process Reaction Method
- 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 (8) . The process reaction curve may be approximated to a time delay D and first order system of maximum tangent slope R.

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 function of R and D , to produce this response , are given in Table 1 .

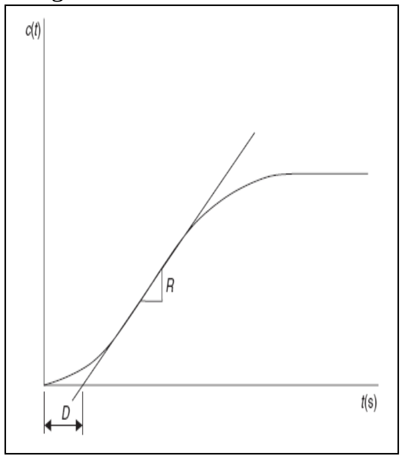

Fig. 8 Process reaction curve

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

Controller type	K_1	T_i	T_d
P	$1/RD$	–	–
PI	$0.9/RD$	$D/0.3$	–
PID	$1.2/RD$	$2D$	$0.5D$

VI. SIMULATION RESULTS

Implementing ATS Tuning for Fuzzy controller

The Simulation MATLAB to control the speed of single phase induction motor using fuzzy-ATS controller with Single-Phase Bridge Inverter and PWM generator at reference speed as shown in figure (9) , according to trials , the system must be in each examined iteration the adaptive tabu search algorithm search the optimal speed . Table (2) shows the ATS parameters' which used to verify the performance of fuzzy-ATS controller parameters.

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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 fuzzy controller tuning parameter using ATS strategy is shown in figure (10) ,

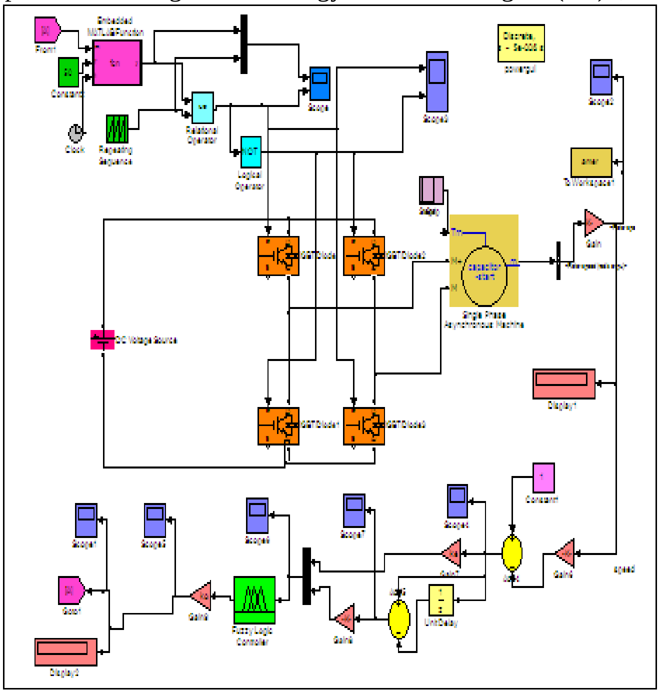


Fig. (9) Simulation MATLAB to control the speed of single-phase induction motor using fuzzy-ATS controller

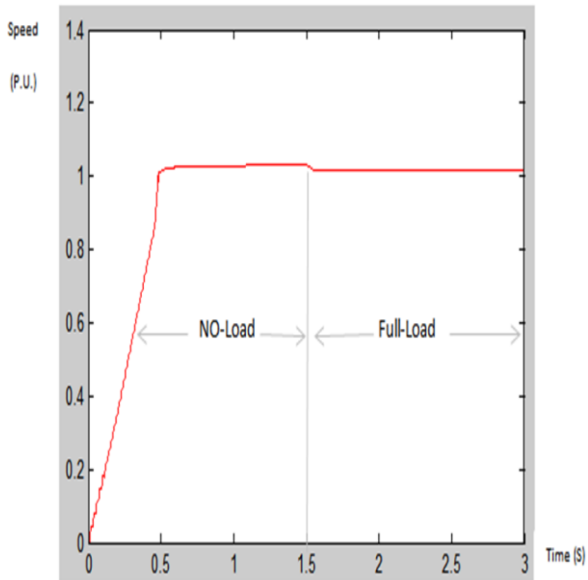


Fig.(10) Speed response of fuzzy Controller tuning parameter using ATS Strategy

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

- Rise time = 0.4327 s
- Maximum overshoot = 0.02 v
- Settling time = 0.5554 s
- Steady stat error = 0.008

VII. COMPARISON BETWEEN ATS TUNING FUZZY CONTROLLER WITH ZIEGLER – NICHOLS CONTROLLER

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

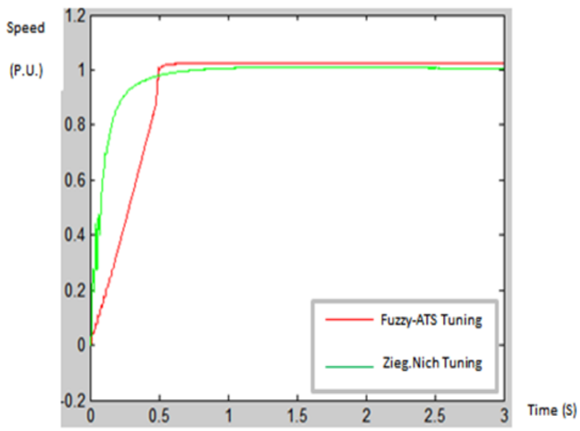
Table (3) The set of good control parameters $K_e, K,$ I for fuzzy-ATS controller and $K_p, I,$ I for Ziegler-Nichols controller at No-load and Full-load

Fuzzy-ATS Controller	k_e	k_{ce}	k_o
	10.7294	0.0107	1.0073
Zieg.Nich controller	k_p	k_i	k_d
	11.4286	5.7143	0.0571

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

Results	No-load		Full-load	
	Zieg.-Nich Controller	PID-ATS	Zieg.-Nich. Controller	PID-ATS
Rise time (sec.)	0.237	0.098	0.097	0.106
Max. Overshoot	0.02	0.01	0.03	0
Settling time (sec.)	0335	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 is shown in figure (11) & figure (12) .



(a)

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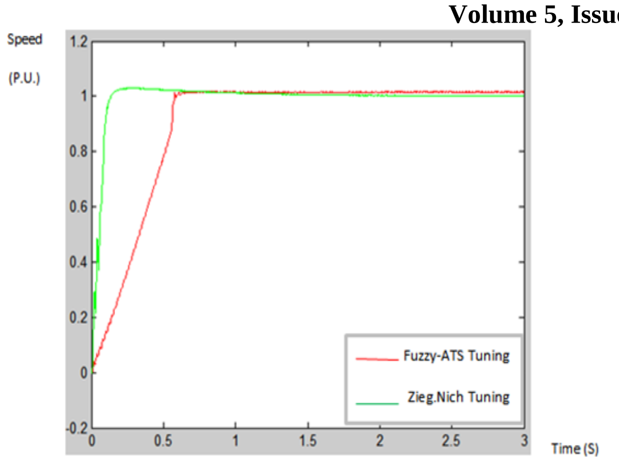

(b)

Fig.(11) Comparing performance of PID-ATS controller and Ziegler-Nichols Controllers at (a) Per-unit No-load , (b) per-unit full-load

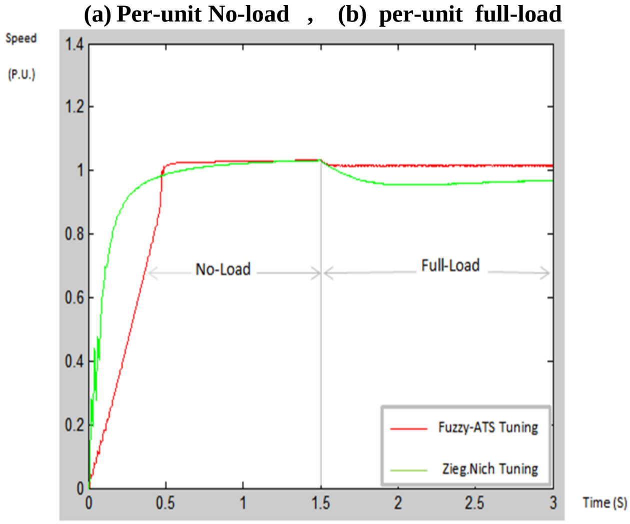

Fig. (12) Comparing performance of Fuzzy-ATS controller and Ziegler-Nichols Controller

VIII. CONCLUSIONS

The speed of a Single phase induction motor drive are control by two methods in this paper , one Ziegler-Nichols controller and fuzzy-ATS controller , and comparison between them , then obtained through simulation of Single phase induction motor are :

- The result show that the proposed controller for the response speed of Single phase induction motor an efficient for the optimal fuzzy controller because can be improve the dynamic performance of the system in a better way .
- By comparison with fuzzy-ATS and Ziegler-Nichols is much more robust in finding optimal control parameters where the quality of fuzzy results differ each run significantly and the ATS results remain relatively stable.
- The ATS-Tuning fuzzy Controller is the best 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 fuzzy is minimized the error when we calculate the step response of the system because the iterations are continuously run until the error minimizes.
- Finally, the proposed controller (fuzzy-ATS) gives very good results and possesses good robustness.

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He received the B.Eng. degree in electrical engineering from Bagdad University in1985.

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Since 2006, he has been with the University of Technology, Department of laser engineering. Since 2008, he has been with the Electrical engineering of Mosul University.

His research interests in optimization, power electronics and intelligent Control.

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