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Speed control of universal motor

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ABSTRACT

Universal Motors (UM) are normally used for driving portable apparatus such as hand tool machines, vacuum cleaners and most domestic apparatus. The importance of UM is due to its own advantages such as high starting torque, very powerful in relation to its small size, having a variable speed; and lower cost. So, this paper focus on UM speed control under variable loading conditions. A mathematical model for UM is designed. Two controllers are proposed for controlling the motor speed, output rate controller and output reset controller. Ant Colony Optimization (ACO) is proposed for tuning the controller's parameters due to its impact on solving different optimization problems. It possesses fast convergence, minimum algorithm parameters required, lower consecution time and give optimal results without needing large number of iterations. The results are compared and discussed accurately, which show the proposed tuning technique work well and give optimal results for both controllers.

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1. INTRODUCTION

In industry, DC-motors are widely applicable due to its speed can be adjusted. Motor-speed control can be done in different arrangments [1]. The universal motors (UM) are an electric rotating machine that analogous to a direct current (DC) motors but it can be work either from (DC) sources or (AC) sources. It combines some advantages like, smaller size, large starting torque, high revolution (approx 30,000 rpm) and have lower costs. Generally,different home appliances are powered by UM, such as electric drills, grinders, vacuum cleaners, saws etc.[2], [3]. UM have widespread application. Its consumption energy of the input power is very low as copared to other types. So, the requirements become increasingly higher for motors with high performances and low-cost controller. Also, recently, SmartHome systems have great attention in the control engineering. Furthermore in the SmartHome system, UM are expected to find wide area applications [3].

Great part of the real-world optimization-problems include multi-conflicting objectives which should be reconciled mutually. [4]. The term optimization means discover the best solution among many possible solutions that are available in the search space. Feasible solutions are those solutions that satisfy all optimization problem constraints. In the optimization problems the best solution could be minimizing the process cost or maximizing the system efficiency. In any optimization problem, a specific function is to be minimized or maximized. The optimized function is defined as th objective function or the performance index or cost function. The optimized function is a quantity such as cost, size, shape, weight, profit, efficiency, output, and so on [5]. Recently, many research papers focus on new natural inspired optimization technique called ant colony optimization (ACO) technique. This optimization technique used for solving different optimization problems successfully. ACO technique is a novel metaheuristic strategy and has been effectively used in different applications especially optimization problems. ACO algorithm imitate the real ants colonies behavior in founding the shortest path between food sources and its nests [6].

Recently, many researchers focus on DC drives control, due to good torque-speed characteristics, simple control arrangement and type's diversity that used in different applications. Different types of controllers are applicable with DC and AC drives controllers range from classical PID family to intelligent controllers [7]. The PID controller is wide applicable in industrial applications due to its simple structure, ease of use and simple simple tuning methods, but it have main disadvantage which is the introduction of big-overshoot as well give oscillation in system when there are a load disturbance especially due to the effects of proportional and derivative kick [8]. This PID controller disadvantages denote a real designing problem in the dc and ac drives controlsystem.

In this article, the proposed solution focus on designing Outputrate controller also output reset controller instead of using PID controller's family. The motivation of use these controllers comes from the fact that these controllers avoid proportional and derivative kick which leads to reduce the system overshoot also these controllers are less sensitive to system disturbance which make them better to use with systems that subjected to load disturbance. ACO is used for tuning the proposed controllers optimally to improve its performance. ACO technique has simple search method that can cover the search space optimallyalso it has lower algorithm parameters as wll as it avoids entrapped in local optima.

Large number of reasearchers give great attention on PIDs controller in the dc and ac-drive control schemes based various optimization strategies. In 2014 Ibrahim et. Al., [9] present tuning method for PID controller based BF and PSO techniques for controlling dc-motor. In 2015 Diego *et. al*., [10] discuss the dc-motor control in robot arm using PID-controller based ACO. In 2016 Suman and Giri [11] proposed dc-motor speed control system using PID controller-based GA. In 2016 Abdulameer *et. al*., [12] present dc-motor control system based PID controller tuned traditionally. In 2018 Shamseldin *et. al*., [13] present BLDCM speed control system using nonlinear PID controller based GA.

2. UNIVERSAL MOTOR MODEL

UM is uncompensated -series motor. Its one type of series-commutation machines. It can operate either from dc or ac source. They are applicable in portable apparatus drive. The electric and dynamic equations of UM are [14]:

$$V(t) = (L_f + L_a)\frac{di_a(t)}{dt} + (R_{f+}R_a)i_a(t) + e(t) \quad (1)$$

$$e(t) = K_1.\omega_m(t).i_a(t) \quad (2)$$

$$T_e(t) = T_L(t) + J\frac{d\omega_m(t)}{dt} + K_2\omega_m(t) \quad (3)$$

$$T_e(t) = K_1.(i_a(t))^2 \quad (4)$$

where; e is the rotational electro motive force emf (V), i_a is the motor motor-current in (A), J is the moment of inertia constant$(kg.m)$, K_1, K_2 is the motor constant (Nm/A), L_a, L_f are the motor armature and field inductance (*H*), R_a, R_f are the motor armature and field resistance (Ω), $T_L$is the load torque (Nm), T_e is electromagnetic torque (Nm), ω_m is the motor angular speed (*rad/s*) and V represent the motor input voltage (V).

3. OUTPUT RATE CONTROLLER AND OUTPUT RESET CONTROLLER

Any system is known to have output rate-control when the output generation in some way depends on the rate at which output changes. Output rate controller can be obtained by feeding back a derivative of output signal of plant and comparing it with proportional error signal. Its introduction often includes the creation of a supplementary loop that lead to multiloop system. It is used for improving the system performance. In servomechanism system, tachogenerator usually provides output rate feedback. This type of controller provides higher gain without poorly affecting the damping ratio that still satisfy the damping ratio specifications besides the steady state performance for step inputs [15]. Output reset controllers (or integral controllers) are used to decrease the steady state error [16]. Output reset controller is achieved by feedingback an integral of output plant signal and comparing proportional error signal with feeding back signal. Figure 1 and Figure 2 show the output rate and reset controllers respectively.

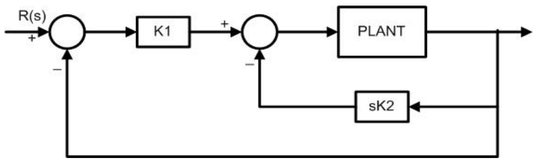


Figure 1. Output rate controller structure

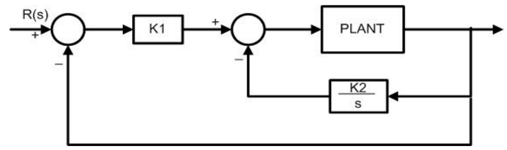


Figure 2. Output reset controller structure

4. ANT COLONY

ACO recently proposed by Dorigo et al. It is a novel population-based technique used for optimization problems solving. It mimics real ants searching behavior for shortest route finding between food centre and nest [17]. Artificial ant's colony, cooperates for best solutions finding, which are a developing ant's cooperative communication. Due to the similarities with nature ant colonies, ACO algorithms are robust and adaptive and can be applied to many problems needs optimization. The major artificial ants features are copy from its natural model. These features are (1) they cooperating individuals colonies, (2) by depositing pheromone they can communicate indirectly (3) based on local moves sequence for finding nearest route from begining to end point [18].

Ants initially discover the area randomly that closed their colony. During discovering process, ants leaving a pheromone path. The pheromone density related to trail length and the discovered food source. An ant selects an exact route depending on the phermone. [19].

Step 1: Initialization of parameters

To calculate ants tour max. Distance use following equation:

$$d_{\max} = \max\left[\sum_{i=1}^{n-1} d_i\right] \quad (5)$$

$$d_i = \left|r - \max(u)\right| \quad (6)$$

Where,

d_i is the nodes distance.

u is unvisited node.

r ispresent node.

Step 2: Initial position generation

This step illustrates the generation of random first position for each ant.

Step 3: Rule of transition

This step illustrates the chosen probability for next node by an ant (7):

$$P_{ij}^{k}(t) = \frac{\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}(t)\right]^{\beta}}{\sum_{ij \in T^{k}}\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}(t)\right]} : i, j \in T^{K} \quad (7)$$

where

$\tau_{ij}(t)$: is the nodes pheromone trial.

$\eta_{ij}(t)$: represent the inverse of distance.

T^{k} : is the effectuated path.

Step 4: Updating local pheromone

This step illustrates the pheromone updating process for each ant. The local pheromone updating is unlike among ants due to different route taken by ants. Each ant initial pheromone is given by.

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \rho\tau_o \quad (8)$$

Step 5: Evaluation of cost function
The best cost function related to shortest path which related to higher pheromone density.

Step 6: Updating global pheromone
The pheromone level is given by:

$$\tau_{ij}(t+1) = (1-\alpha)\tau_{ij}(t) + \alpha\Delta\tau_{ij}(t) \quad (9)$$

Step 7: ACO algorithm termination or stopping criteria
In this step the program (ACO algorithm) will be ended when the max. Number of iterations is achieved or the optimal solution is attained without stagnations of ants.

5. SIMULATION AND RESULTS

When using transfer function to model the plant, some approximation should be taking place such as ignore all initial conditions for plant model. This approximation will give an acceptable result for plant response in control studies. While when using mathematical model for modelling the complete control system, all initial conditions are considered when modelling the system. So, the obtained results are more accurate and the mathematical model are close to actual plant behavior. So, in this article a focus is made on a mathematical modelling of the system due to advantages of this approach. The complete model of the UM is designed based motor electric and dynamic equations (see section 2) using MATLAB/SIMULINK toolbox. Output rate and output reset controllers are designed also for constructing the motor closed loop control system. ACO strategy is build using matlab m-file and linked with Simulink model of motor control system. Integral time absolute error is used as performance indices. Universal motor used parameters mentioned in Table 1.

Table 1. UM parameters

Universal motor parameters	Symbol	Unit	Value
Motor Power	P	hp	5
Motor input voltage	V	V	220
rotor current	ia	A	22
Motor speed	ωm	Rad/s	188.4
rotor Resistance	Ra	Ω	0.6
Field Resistance	Rf	Ω	0.4
Rotor Inductance	La	H	0.03
Field Inductance	Lf	H	0.002
Moment of inertia constant	J	Kg.m2	0.0465
Viscous Friction Coef.	K2	Nms/rad	0.005
Motor Constant	K1	Nm/A	0.027

The ACO algorithm parameters that used for tuning the output rate controller and output reset controllers are listed in Table 2, while the obtained tuned controllers' parameters based ACO technique are mentioned in Table 3.

Table 2. ACO algorithm parameters

ACO algorithm parameters	Output rate controller	Reset controller
Number of ants (m)	10	10
Number of nodes (n)	100000	100000
Maximum iteration (tmax)	10	10
Pheromone decay parameter (α)	0.8	0.8
pheromone relative importance against distance parameter (β)	0.2	0.2
Heuristic-coefficient (ρ)	0.7	0.7

Table 3. The obtained controllers' parameters based ACO

	Output rate controller	Output reset controller
K1	16.336	297.1144
K2	0.3177	0.000008086

The Fitness function plot for tuning the output rate controller and output reset controllers are illustrated in Figure 3 and Figure 4 respectively. From the two fitness plots, it is clearly that after the second or third iteration, the fitness function plot is decreased sharply. It is obvious that the cost function plot is decrease after the second or third iteration and approximately steady. This prove the fast convergence ability of the ACO algorithm which leads to obtain the optimal solutions without resorted to increase the number of iterations which leads to lower consecution time of tuning process. While other optimization strategies normally need high number of iterations for converge. From all these proves, ACO have superior features than other optimization strategies.

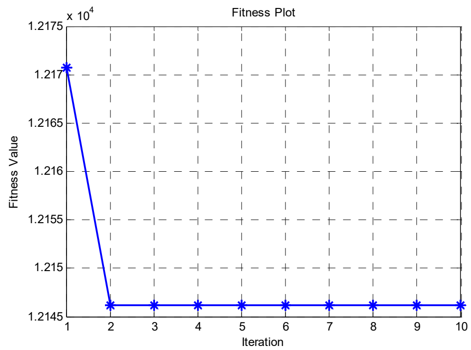


Figure 3. Fitness plot for tuning output rate

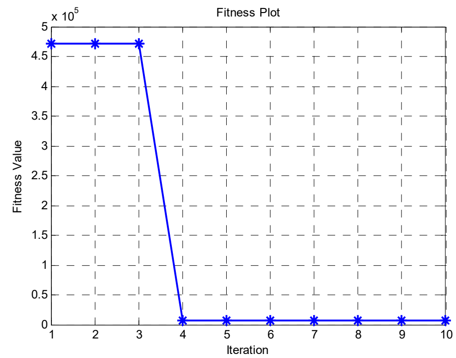


Figure 4. Fitness plot for tuning output reset

UM is tested by applying different loads to show the robustness of the controllers that tuned based ACO technique under different loading conditions. Figure 5 and Figure 6 shows a comparison in speed responses under different loads using output rate and output reset controllers respectively.

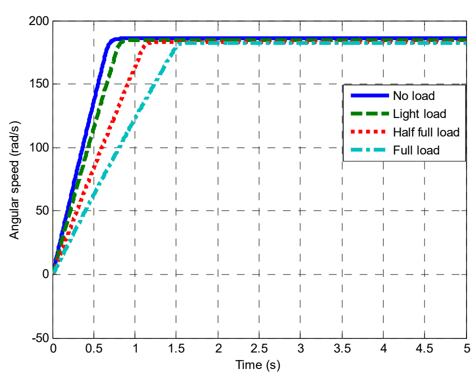


Figure 5. UM speed using output rate controller

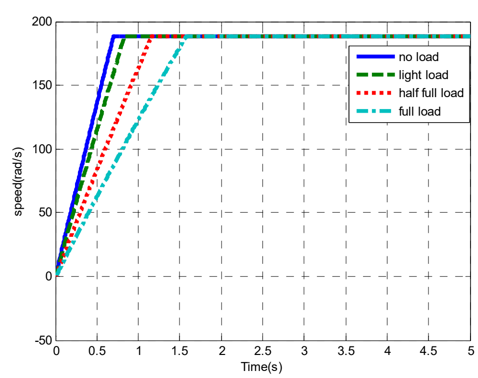
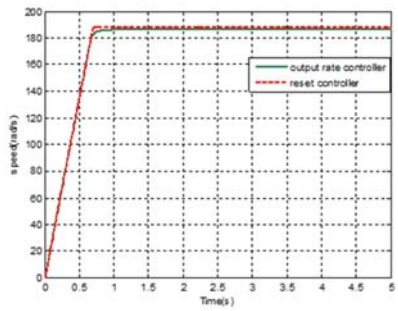
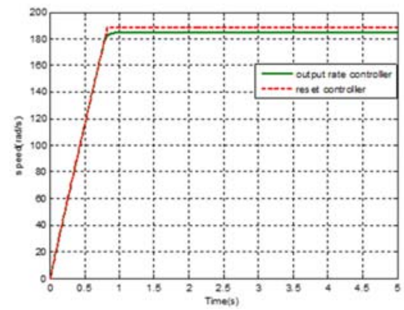


Figure 6. UM speed using output reset controller

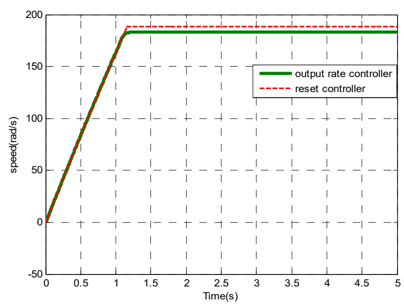
From results it is clearly that, for both tuned controllers there are a clear improvement in system transient and steady state performance for all loading conditions. Both tuned controllers give zero percent over shoot and under shoot, slight rise time and settling time and fast response produce for all load disturbances. Figure 7 illustrate speed response comparison of UM with both controllers under different loads.



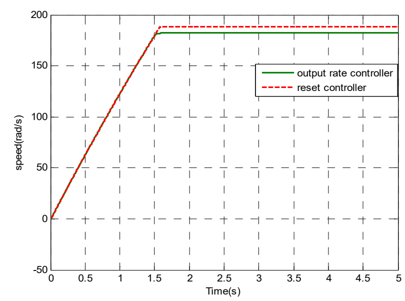
(a) UM speed responses under no load



(b) UM speed responses under light load



(c) UM speed responses under half full load



(d) UM speed responses under full load

Figure 7. Comparison of UM speed responses under different loads using the two controllers

From Figure 7, it is obviously that the UM speed responses with the two controllers are approximately similar with very small error for all load disturbances. The two proposed controllers are appropriate for controlling systems subjected to load disturbances.

6. CONCLUSIONS

This paper focus on mathematical model designing because its more reality to actual plant without resorted to ignore any initial condition. For appropriate UM speed control, an output rate controller and output reset controllers are used due to its impact on improving the transient and steady state performance of the system. These controllers have some advantages over other controllers such simple construction, lower complexity, improve the system transient and steady state performance and required simpler tuning. ACO technique is used for optimal controllers tuning to get best system performance. Among many natural inspired optimization techniques, ACO have many advantages such as, low algorithm parameters required, minimum iterations required, fast convergence and low execution time. All these advantages make this technique more appropriate for solving different optimization problems. The results show an obvious improvement in system performance by reducing rise time, settling time and eliminate peak overshoot for different applied loads between no-load and full-load. The system is tested with loads changes gradually at different times as well as at changing the reference speed from below rated speed till over rated speed. The UM with controllers based ACO technique shows an optimal performance improvement for different loading tests. The two tuning controllers give optimal results for controlling the motor speed under various loading applications.

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