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A Recent Approach to Repetitive Control Strategy for Induced Draft Fan

[1]G. Thanigaivel, [1]M. Vijayakarthick, [1]S. Sathishbabu and [2]P.K. Bhaba

[1]Department of Electronics and Instrumentation Engineering, Annamalai University, Annamalai Nagar, India
[2]Department of Chemical Engineering, Annamalai University, Annamalai Nagar, India

Abstract: In this work, design and development of controlling induced Draft fan in a tea industry is proposed. The aim of this work is to control the Induced Draft Fan in a different periodic input signals. An idea of New Modified Repetitive Control Strategy (NMRCS) of ID fan is introduced. Based on the nonlinearities present in the system and the input reference signal is periodic in nature, the conventional type controllers gives poor satisfactory time-varying trajectory speed control. To examine the proposed technique, simulation runs are carried out and performance measures are investigated in terms of tracking error and the results confirm the dominance of NMRCS controller. A robustness of the proposed control strategy is also tested.

Key words: ID fan · NMRCS · Repetitive control · Rational factor

INTRODUCTION

Induced Draft Fan is one of the rotating equipment in a tea industry. It maintains the temperature in the drying unit as per process requirement. The flue gases generated in the air heating stove to be sucked by Induced Draft fan and to maintain required temperature inside dryer.

The tea industries generate waste in the different forms like Green leaf waste, Dust, Noise, Fermenting aroma, solid waste in this most of as is not creating any problems to environment. But co2 one of the major constituent of the GHG emission through chimney takes considerable attention in their environmental pollution, because most of the industries using coal, Firewood and lignite for the thermal energy sources. The furnaces in the tea industries are installed with very long back and it operating with very low efficiency that claims the higher amount of flue gases with very high temperature that mix with the atmosphere, this increase the atmospheric air temperature and also increasing the co2 level in the surrounding areas.

Therefore, control of temperature is predominant in the tea industry. In general, controller [1] may also effort to reduce the magnitude of actuator signals, the time taken for the output to reach its desired value or the effect of disturbances. Usually the conventional control is based on the principle of feedback, where output errors are fed, through a controller, back to the input. The cost of this feedback is the possibility of causing instability, where bounded inputs to the system are able to produce unbounded outputs, even for a priori stable systems. This conventional controller usually leaves large transient errors when the system is subjected to periodic disturbances. Errors may be due to interactions, delays and other elements of dynamics that prevent rigid tuning. To overcome this problem, Repetitive controllers based on the Internal Model Principle (IMP) are placed in the control loop. The main contributions of the work presented in this paper are precisely implementation of the New Modified Repetitive Control Strategy in an ID fan and analyzes the tracking performance. In section 2 the mathematical model of ID fan is summarized. The design and structure of New Modified Repetitive Control Strategy is detailed in section 3. Simulation results are analyzed in section 4 to exemplify the better performance of the NMRCS in closed loop. Finally, section 5 concludes the paper.

Identification of Model Parameters and Controller Settings

Mathematical Model Description: The fan model is taken from the simulation software HVACSIM+. The induced draft fan model is expressed as follows [2].

Corresponding Author: M. Vijayakarthick, Department of Electronics and Instrumentation Engineering, Annamalai University, Annamalai Nagar, India.

$$C_f = \frac{\omega}{\rho N D^3} \quad (1)$$

$$C_h = \frac{1000 P_f}{\rho N^2 D^2} \quad (2)$$

$$C_h = a_0 + a_1 C_f + a_2 C_f^2 + a_3 C_f^3 + a_4 C_f^4 \quad (3)$$

$$n_f = e_0 + e_1 C_f + e_2 C_f^2 + e_3 C_f^3 + e_4 C_f^4 \quad (4)$$

$$E_f = \frac{\omega P_f}{\rho n_f} \quad (5)$$

PD Controller Design: The PD controller parameters (Kc and Kd) are designed by using a optimization tool in MATLAB platform [3] and model parameters are automatically optimized to get the desired performance requirements as given in Table 1. The optimized PD controller settings are $K_c = 2.521$ and $K_d = 1.984$.

Table 1: Performance specification for PD control system

Rise time (tr)	20
Settling time (ts)	22.2
Over shoot (Mp)	20%

Repetitive Control Strategy (RCS): Repetitive control strategy [4]-[6] is considered for tracking a periodic input signal and eliminating a periodic load signal. The Repetitive Control Strategy (RCS) design is based on the Internal Model Principle (IMP) and it is proposed by Wonham and Francis [7]. The IMP states that if any exogenous signal can be regarded as the output of an autonomous system, the inclusion of the model of the signal in a stable closed-loop system can promise ideal tracking or complete elimination of the periodic signal.

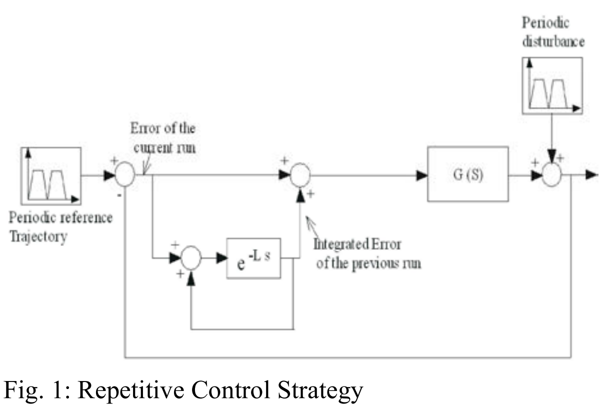

Fig. 1: Repetitive Control Strategy

The RCS includes the factor $\frac{e^{-Ls}}{1-e^{-Ls}}$ which has 0poles at jk, k = 0, ± 1,….., ± ∞ (corresponding to the harmonic and sub harmonics of the basic period L), the controller can track any periodic signal and reject any disturbance of period L. Based on this concept, RCS is constructed with a model of $\frac{e^{-Ls}}{1-e^{-Ls}}$. The basic Repetitive control structure shown in Fig. 1.

Implementation of New Modified Repetitive Control Strategy (NMRCS): The modelling of ID fan motor is uncertain for high frequency signals. At high frequencies, noise signal will affect the response, which leads to instability of ID fan. To meet out this trouble, a low-pass filter (Q(s)) is introduced to the existing RCS loop and to make sure the ID fan stability. This structure is named as Modified Repetitive Control Strategy (MRCS) [8]. To enhance the stability of MRCS based on sensitivity, a New Modified Repetitive Control Strategy [9] is proposed and given in Fig. 2.

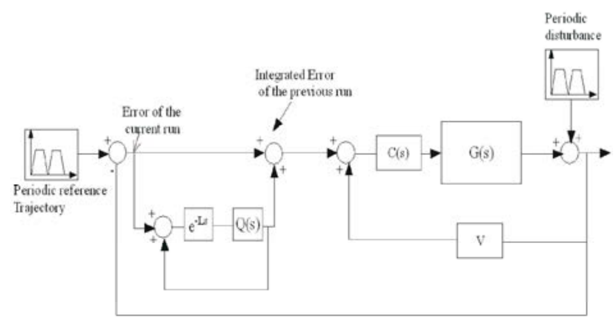

Fig. 2: New Modified Repetitive Control Strategy

The sensitivity function of the proposed scheme is given by

$$s(jw) = \frac{e}{d} = \frac{-1}{1 + \frac{PC}{1-PCV}\left[1 + \frac{e^{-jwTd}}{1-e^{-jwTd}}\right]} \quad (6)$$

The sensitivity function described by equation (6) is plotted as shown in Fig. 3. In the magnitude response, the sensitivity at the period frequencies is smaller than the MRCS configuration. This means that the errors with frequencies between the period frequencies are minimized with the NMRCS than the MRCS.

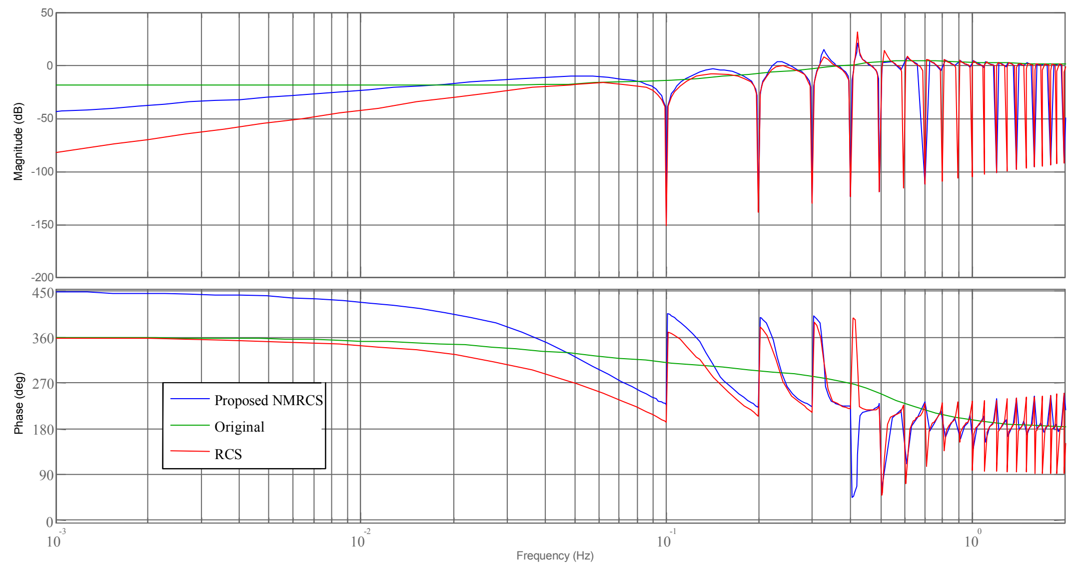

Fig. 3: Magnitude of the sensitivity function

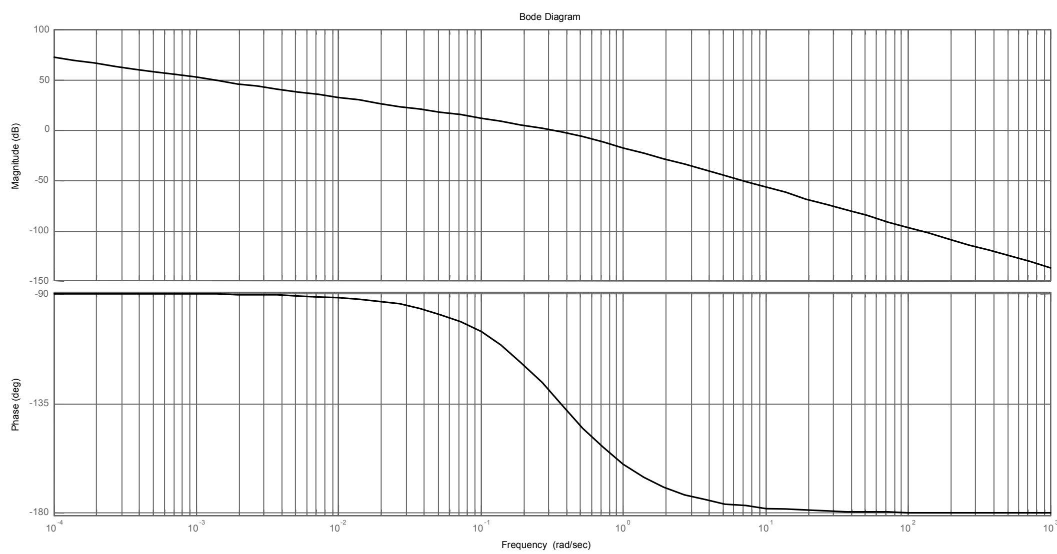

Fig. 4: Frequency response of ID fan

Design Procedure and Guidelines

Design of Low Pass Filter: A first order continuous time low pass filter is considered here. The cut-off frequency of low pass filter is obtained from the Bode plot of the ID fan motor system as shown in Fig. 4. It is found to be 0.33.

Design of Rational Factor: By utilizing a simple optimization technique the rational factor (V) is obtained by considering minimum tracking error as an objective function. The identified value of V for ID fan is 0.2.

RESULTS AND DISCUSSIONS

In the simulation test, the input reference periodic sinusoidal signal with known period (L = 62) and amplitude (V_{pp} = 5) is generated and applied to ID fan with NMRCS based PD mode. The tracking response is recorded in Fig. 5. In addition to that an simulation runs of MRCS based PD mode and conventional PD mode control loop are carried out and responses are traced in Fig. 6 and Fig. 7.In all the cases the nominal operating point of 40% of speed is maintained.

From the responses, the tracking errors are obtained with respect to time and results are charted in Fig. 8 and Table 2. It is observed that NMRCS in control loop is capable of tracking dynamic periodic reference trajectories with minimum error. To inspect the robustness of the NMRCS, a simulation runs of the ID fan for a periodic trapezoidal signal with known periods and amplitude values (L= 50,Vpp= 5) is carried out. Figures (9 to 12) justify the robustness of incorporation of NMRCS in control loop.

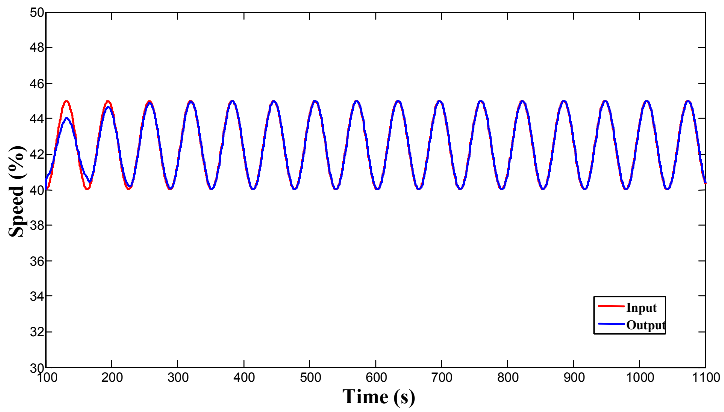

Fig. 5: NMRCS: Simulation tracking response of sinusoidal periodic reference trajectories [Period (L) = 62, Amplitude (A) = 5, OP = 40%]

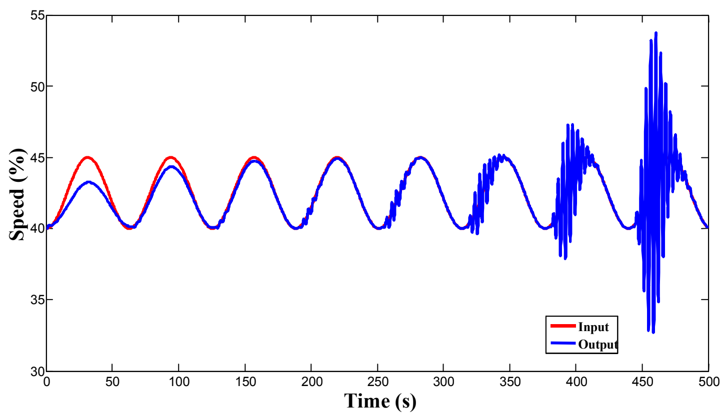

Fig. 6: MRCS: Simulation tracking response of sinusoidal periodic reference trajectories [Period (L) = 62, Amplitude (A) = 5, OP = 40%]

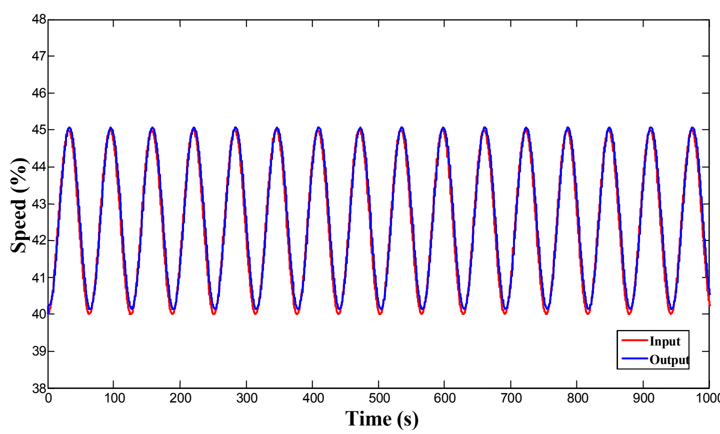

Fig. 7: PD: Simulation tracking response of sinusoidal periodic reference trajectories [Period (L) = 62, Amplitude (A) = 5, OP = 40%]

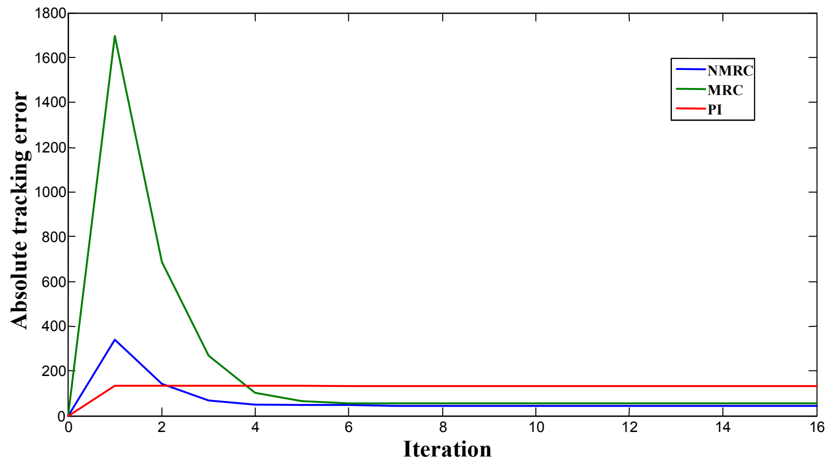

Fig. 8: Simulation absolute tracking error responses of sinusoidal periodic reference trajectories [Period (L) = 62, Amplitude (A) = 5, OP = 40%]

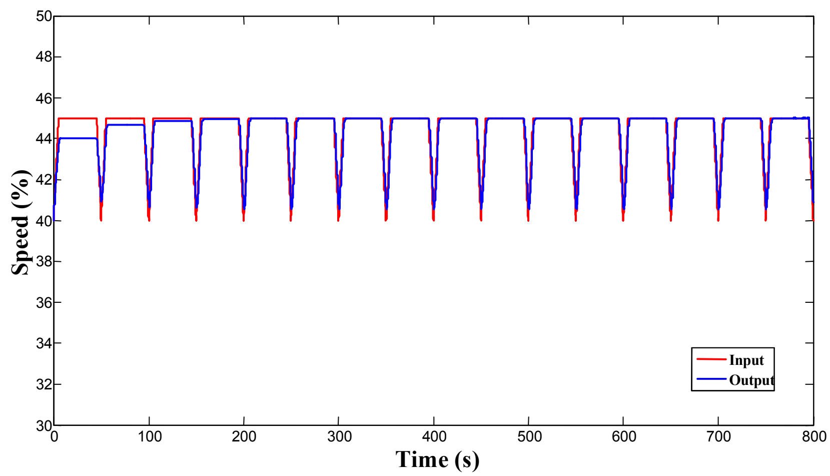

Fig. 9: NMRCS: Simulation tracking response of trapezoidal periodic reference trajectories [Period (L) = 50, Amplitude (A) = 5, OP = 40%]

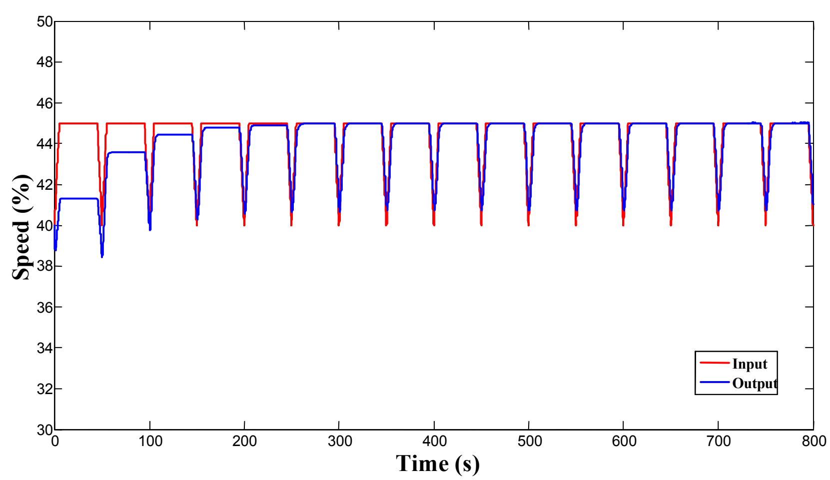

Fig. 10: MRCS: Simulation tracking response of trapezoidal periodic reference trajectories [Period (L) = 50, Amplitude (A) = 5, OP = 40%]

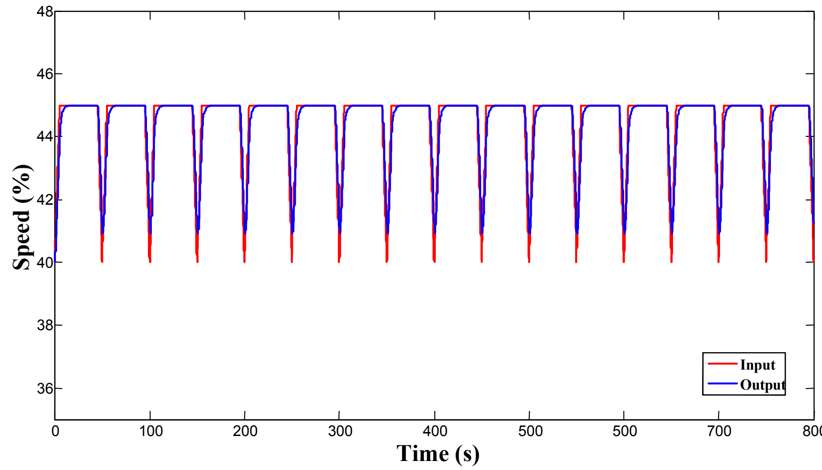

Fig. 11: PD: Simulation tracking response of trapezoidal periodic reference trajectories [Period (L) = 50, Amplitude (A) = 5, OP = 40%]

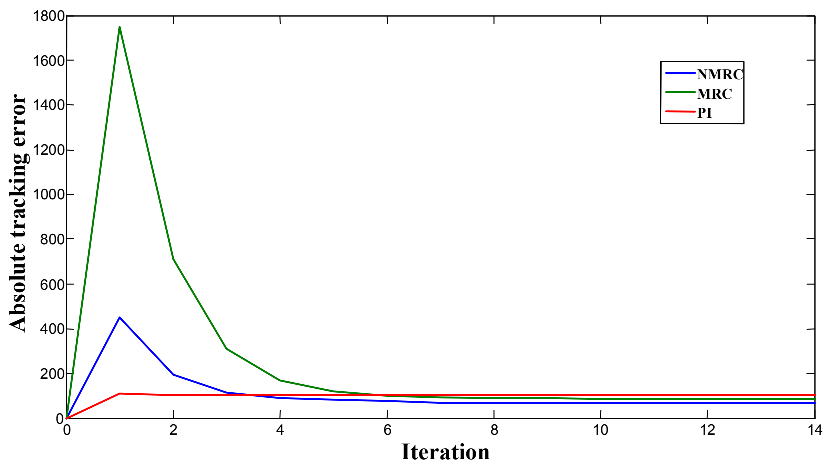

Fig. 12: Simulation absolute tracking error responses of trapezoidal periodic reference trajectories [Period (L) = 50, Amplitude (A) = 5, OP = 40%]

Table 2: Performance analysis of different control strategies

Control strategies	Sinusoidal L: 62 & Amp A: 5	Trapezoidal L: 45 & A: 5
NMRC	*ATE: 63*	*ATE: 159*
MRC	ATE: 70	ATE: 188
PD	ATE: 160	ATE: 246

CONCLUSION

In this work, a new modified repetitive control strategy is proposed and evaluated using simulation for ID fan. An input of periodic reference signal to proposed controller is executed and performance analysis is done in terms of absolute tracking error. A comparative study with conventional PD is also carried out. The results clearly show the domination of the proposed NMCS in ID fan. Robustness of the NMRCS is also investigated.

Nomenclature:

Cf: Dimensionless air flow rate [-]
Ch: Dimensionless pressure head [-]
D: Diameter of fan wheel [m]
Ef: Fan power consumption [kW]
f: Output frequency of inverter [Hz]
N: Fan rotation speed [r/s]
Pf: Fan pressure head [Pa]
w: Fan supply air mass flow rate [kg/s]
ñ: Air density [kg/m3]
a_0, a_1, a_2, a_3, a_4 – Fitted coefficients using fan specification data
e_0, e_1, e_2, e_3, e_4 – Fitted coefficients of fan efficiency equation using fan specification data

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