



Ant colony based feedback controller design for soft-starter fed induction motor drive

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ABSTRACT

The objective of this work is to design and implement a closed loop system for induction motor starting at rated current. Thyristorized AC voltage regulator is used as the starting equipment and motor current regulation is carried out using an optimally tuned Proportional-Integral (PI) controller. Since, AC voltage controller fed starting of induction motor is a non-linear process, identification of optimal values of PI controller constants is performed using a novel ant colony based optimization technique. The complete drive system including AC voltage controller fed induction motor in conjunction with optimal PI controller is first simulated in MATLAB and subsequently verified experimentally. The successful implementation with a low cost microcontroller illustrates the feasibility of the new approach.

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1. Introduction

The methods of starting of three-phase induction motors are generally classified into four basic categories [1]: direct online starting, electromechanical reduced voltage starting, solid-state reduced voltage starting and variable-frequency-drive (VFD) starting. The cheapest way is direct online starting, but the major disadvantage is large initial current surge leading to voltage dips in the supply system. Electromechanical reduced-voltage starting comprises auto-transformer starting, star/delta starting and resistor/reactor starting. Among these, star/delta starting is more popular since it is cheap, compact and causes no power loss. However this method can be applied only for normally delta-connected stator provided with six leads. Conventional starting elements require some type of mechanical switch or contact and have several drawbacks [2,3], such as need for frequent inspection and maintenance, non-simultaneous switching of motor phases to the supply, failure in the moving parts due to large amount of switching etc.,.

Availability of high-power devices has led to the development of solid state starters replacing conventional starters. An earlier work in this direction is seen in [4,5]. The solid state starter consisted of a pair of back-to-back connected SCRs and the firing angle of SCRs was varied to control rate of change of KVA with respect to time. Such a scheme is examined for pulp and paper industry in [6]. A solid state voltage contactor employing anti-parallel SCRs is

given in [7]. The concept of use of SCR voltage regulator with firing angle control for smooth induction motor starting is labeled as “soft starter” and a closed loop soft starter with fuzzy logic controller is available in [8]. A closed loop optimal soft starting ac voltage controller fed induction motor drive based on voltage across the thyristor is seen in [9]. While earlier works were confined to current limit starting, performance enhancement of starting torque profile was later addressed [10,11]. Numerical solution method is attempted in [10] for improved starting current and torque profile whereas the method suggested in [11] consists of two parts: a linear initial firing angle scheme which eliminates starting torque ripples and a current control strategy which consists of successive co-sinusoidal and constant function segments of triggering angle of SCRs. A soft starter with voltage and power factor angle as feedback signals is given in [12], whereas starting torque optimization is carried out in [13]. The work in [14] explains the use of Artificial Neural Network (ANN) for the generation of SCR firing angles for soft starting. Soft starters are also employed for energy saving too [15,16]. While the schemes in [4–7] are of open loop type, the soft starters in [8–14] work in closed loop mode. The closed loop control strategies are obtained by repeatedly simulating the motor model several times and employing trial and error based approach.

While the soft-starter has been increasingly employed in the industries now-a-days, the design procedure of feedback controller for rated current starting is not available in literature. This is important in particular because, AC voltage controller fed induction motor drive system is described by a fifth order differential equation and is highly non-linear. This demands a detailed design and implementation of a feedback controller for soft-starter fed

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Nomenclature

V_{ds}	direct axis component of stator voltage
V_{qs}	quadrature axis component of stator voltage
i_{ds}	direct axis component of stator current
i_{qs}	quadrature axis component of stator current
i_{dr}	direct axis component of rotor current
i_{qr}	quadrature axis component of rotor current
r_s	stator winding resistance
r_r	rotor winding resistance
L_m	magnetizing inductance
L_s	stator winding inductance
L_r	rotor winding inductance
ω_r	motor speed in rad/s
T_e	electromagnetic torque
T_L	load torque
P	number of poles
J	moment of Inertia of the motor
α	firing angle
I_r	actual motor current
I_r^*	rated motor current
e	error
α_0	initial firing angle
K_p	proportional gain
K_i	integral gain
m	ant population size
ρ	evaporation constant
τ	pheromone level
p_t	threshold probability

induction motor drive. In this paper, the feedback controller design is formulated as an optimization problem and the solution is achieved to obtain good dynamic response. A close examination of the available research work indicates that systematic design and implementation of a soft-starter with PI controller is not available in the literature. This paper proposes an optimization model for PI controller based motor current regulation during motor starting. The optimization model makes use of d - q axis model for evaluating objective function and controller constants are then iterated through ant colony optimization (ACO) [17].

We have employed a modified ACO for the design of a PID controller to be used in the closed loop of a boost converter for output voltage regulation. The concept of a group of ants as a colony of cooperating agents was first proposed by Dorigo et al. [17–22]. It was observed that real ants, which are almost blind and have very simple individual capabilities, are capable of finding shortest path between their home colony and food source. When an ant moves, it deposits a chemical substance called pheromone on its path which can be detected by other ants and their movements are biased by pheromone trails left on the ground by the preceding ants. This pheromone laying mechanism thus acts a channel of communication between the ants. While each ant starts essentially at random, the one that finds food source first returns to its nest first and this ant therefore, makes many more traverses between the food and nest. Thus, the pheromone accumulation in this path becomes stronger and all ants eventually use this shortest path. The convergence of all ants to a single, shortest possible path can be attributed to the collective behavior of ants in a colony; ants coordinate their activities exploiting indirect communication among them through pheromone laying mechanism. Algorithms based on ACO had been developed and tested successfully for a variety of combinatorial optimization problems such as power electronic circuit design [19], self-structuring antenna [20], fuzzy controller design

[21] etc. Various swarm intelligence techniques are available in [22–25].

While ACO is employed for a variety of applications, such methods are suitable for discrete optimization; in discrete optimization, distinct points already exist as possible solutions and the task is to identify one of the many combinations of array of these points which are best suited to the problem. Thus when initially ACO concept was applied to discrete optimization tasks, the ant moves from one distinct point to the next. In this paper, the feedback controller design for a soft-starter fed Induction motor drive is formulated as an optimization problem and the existing ACO is tailored suitably for continuous optimization of the PI controller parameters namely K_p and K_i which are not generally discrete. With continuous optimization, only bounded solution space is available where the solution has to be continuously explored. Extensive simulation and experimental works were carried out with different types of disturbances using the feedback controller identified through ACO. The results show that the proposed design methodology gives a robust controller which is far superior to traditionally designed controller.

Extensive simulation results are provided to validate the proposed method. In addition, a prototype soft-starter with microcontroller based PI controller is fabricated in the laboratory and experimental results are recorded to validate the simulation findings.

2. Ant colony based algorithm for PI controller design

2.1. Modeling of soft-starter fed induction motor with PI controller

The schematic of three-phase AC voltage controller fed induction motor starting using closed loop current controller is shown in Fig. 1. Here, the power converter employed is a three-phase AC voltage regulator employing SCRs. The SCR firing angle is varied to adjust the stator voltage applied to the motor. The AC voltage controller consists of six SCRs labeled as $T_1, T_1', T_2, T_2', T_3$ and T_3' . The SCRs T_1 and T_1' are triggered at a delay of α and $\pi + \alpha$ respectively with reference to the zero crossing of R-phase voltage, V_{RN} . The SCRs T_2 and T_2' are triggered at a delay of $(2\pi/3) + \alpha$ and $(2\pi/3) + (\pi + \alpha)$ respectively. In a similar manner, the SCRs T_3 and T_3' are triggered at a delay of $(4\pi/3) + \alpha$ and $(4\pi/3) + (\pi + \alpha)$ respectively. The heart of the closed loop system is PIC16F876A micro controller which works as digital PI controller as well as firing pulse generator. The R-phase voltage, V_{RN} is stepped down and converted into a digital pulse using Zero Crossing Detection (ZCD) circuit and this pulse is fed to the pin RC₀ of the microcontroller. The microcontroller senses the status of this pin at each time and once zero crossing signal has come, it starts producing six firing pulses through RB0 to RB5 with a delay angle, α computed by the PI controller realized in the microcontroller.

The schematic of three-phase AC voltage controller fed induction motor starting with closed loop current controller is shown in Fig. 1. Here, the AC voltage controller fed induction motor drive model is represented through equations [26–27] given below:

The stator voltages, V_{ds} and V_{qs} are given by,

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{rs} \\ V_{ys} \\ V_{bs} \end{bmatrix} \quad (1)$$

where V_{rs} , V_{ys} and V_{bs} are motor terminal voltages and depend on the value of α .

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