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Review TEE

Optimization of V/F Control in Asynchronous Motors Using Adaptive Bee Colony Optimization

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Abstract

Asynchronous motors play a pivotal role in various industrial applications, utilizing electromagnetic induction to convert electrical energy into mechanical energy. This study provides an in-depth exploration of their design principles, focusing on the rotor, stator, and coil configurations. Induction motors are categorized into single-phase and three-phase types, each suited to different power supply configurations and operational requirements. The study outlines a comprehensive methodology for modeling and simulating induction motor behavior using MATLAB/Simulink, emphasizing the implementation of V/F control strategies. Specifically, the study introduces the Adaptive Bee Colony Optimization algorithm for tuning the Proportional Integral (PI) controller to achieve optimal speed control. Simulation results compare traditional PI control with the proposed optimization algorithm across varying speed conditions, demonstrating improvements in motor efficiency and stability.

Keywords: Asynchronous motors, V/F control, Adaptive Bee Colony Optimization, PID controller, MATLAB/Simulink simulation, industrial applications

INTRODUCTION

An asynchronous motor is an electrical machine that uses alternating current (AC) and is driven by a magnetic field. They employ electromagnetic induction to transform electrical energy into mechanical energy and are composed of a rotor, stator, and coils. AC induction motors are efficient, flexible and simple in design; this allows them to meet the requirements of almost any electrical application [1]. The stator is the outer, stationary chamber in which the rotor rotates. It consists of an electromagnet ring formed in a cylindrical shape to create a magnetic field. Copper wrapped around the cylinder forms magnets with one pole of each magnet facing the center [2]. When alternating current passes through the coils, they create a pair of alternating magnetic poles. Alternating magnetic poles create a rotating magnetic field of equal intensity. The rotor also has a series of electromagnets arranged around the cylinder in the stator. The magnetic field opened in the rotor is attracted by the magnetic field created by the stator.

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Working Principle

The working concept of an induction motor is that torque is obtained through electrical induction, which is caused by the rotational magnetic field of the stator winding, and requires the AC in the motor's rotor to produce it.

Different Types Induction Motor

Types of induction motors are shown in Figure 1. Motors can be divided into two categories: single-phase and three-phase models. A 1-phase induction motor is connected to a single-phase AC power

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source, as their name implies, whilst a 3-phase induction motor can be connected to a three-phase AC power supply. Block diagram for variable frequency drive is shown in Figure 2. Again, these sorts of induction motors are separated into a few smaller groups. Whereas single-phase is split into four groups, three-phase is separated into two variants [3]. Block diagram of variable frequency drive is shown in Figure 3.

MATERIALS AND METHODS (WORKING PRINCIPALE IM)

In order to conduct IM studies and make a correct diagnosis, a CAD model was created to verify the accuracy of the diagnosis, a model was created in the form of a parametric platform of the body before the design, and a robust model was created. The IM AIR63V2 driver was chosen as the basis of the model, as it met all the requirements and was very useful for learning. The IM AIR63V2 passed, and the real model (obtained from some insignificant purchases) became the basis of the CAD design. Figure 4 shows the data flow diagram of the IM design [4].

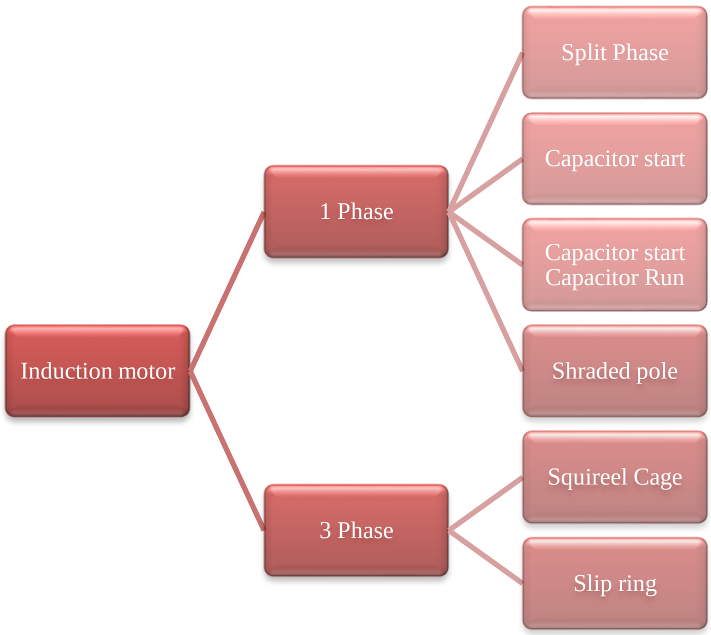

Figure 1. Types of Induction Motor [3].

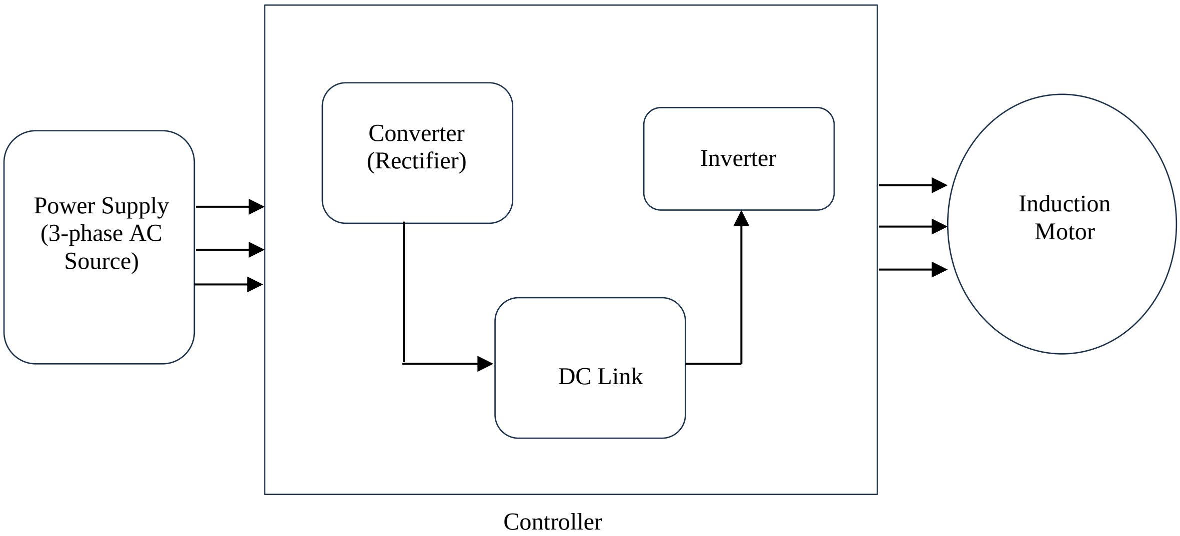

Figure 2. Block diagram for variable frequency drive.

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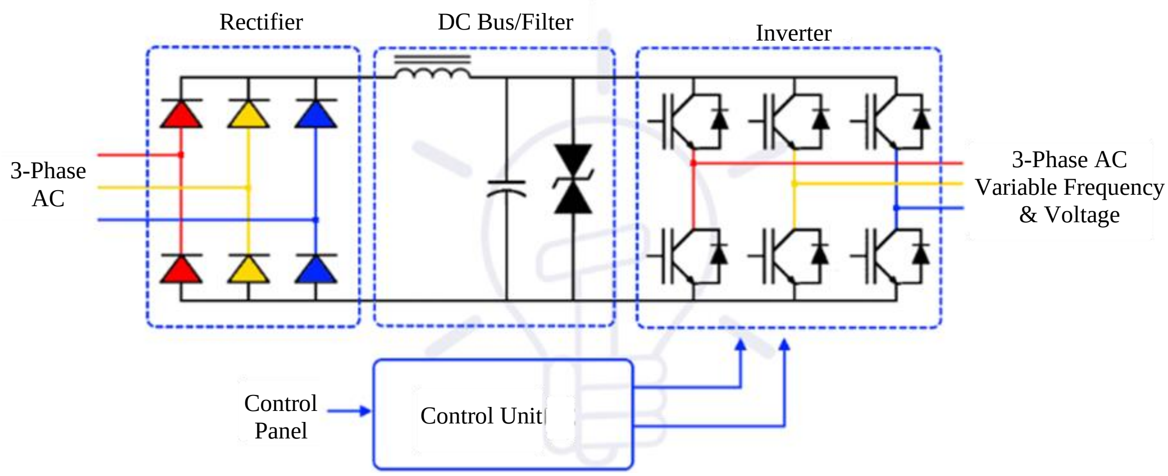

Figure 3. Detail block diagram of variable frequency drive (VFD).

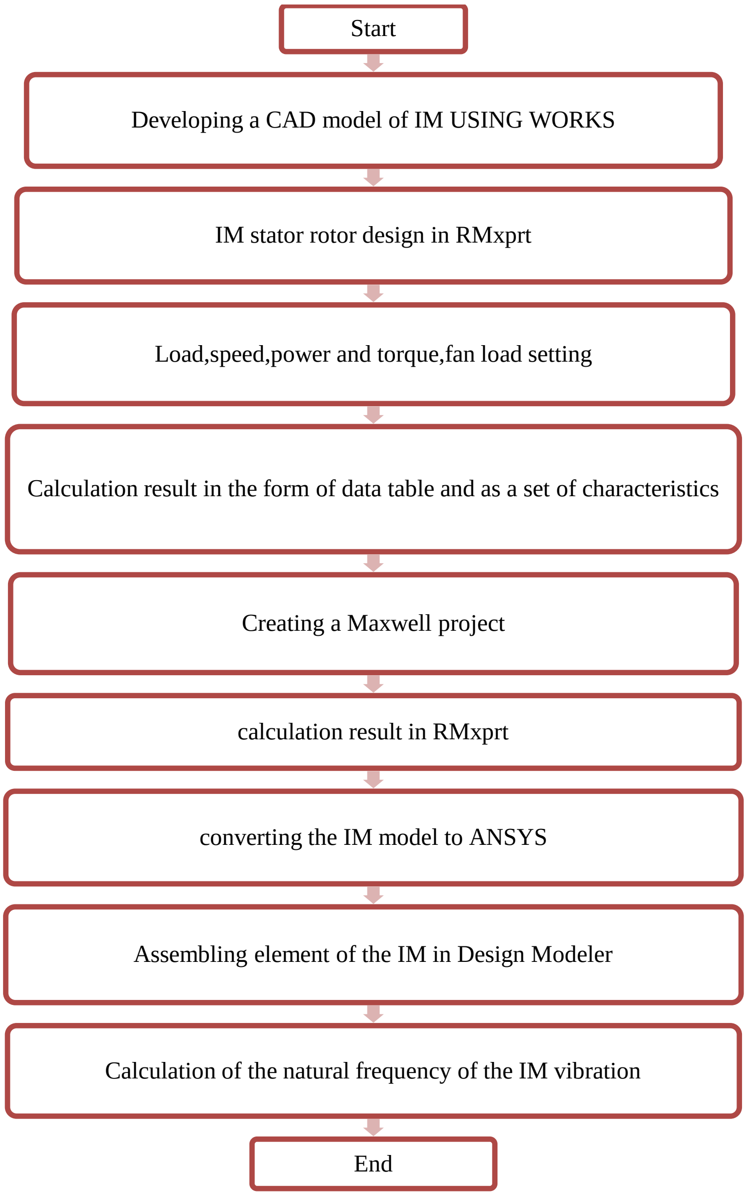

Figure 4. A diagram of the information flow of the design of the IM.

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LITERATURE REVIEW

Baiju *et al*. highlight the inefficiencies of typical induction motors operating at full load capacity in industrial settings, leading to substantial energy wastage and harmonic production [1]. They propose a Variable Frequency Drive (VFD) system to mitigate these issues by optimizing energy consumption while maintaining rated power through V/F control.

Hamim *et al*. emphasize the critical role of asynchronous motors in the automotive industry but note challenges in speed control and energy efficiency [2]. Their study introduces a VFD system integrated with a three-phase motor using MATLAB simulation, demonstrating significant reductions in starting current and improvements in speed regulation.

Kirange *et al*. (2023) conduct a comprehensive study on power quality improvement in the textile industry using VFD-fed induction motors [5]. They highlight the detrimental effects of harmonics from nonlinear loads and advocate for VFD systems to enhance power quality, reduce energy consumption, and optimize operational processes, especially in Indian textile mills.

Manocha *et al*. present a reliability analysis of a Variable Voltage Variable Frequency Drive (VVVFD) system in industrial applications [6]. Their research focuses on assessing failure modes and reliability characteristics through theoretical modelling and empirical data, aiming to enhance system uptime and performance through informed maintenance strategies.

Reddy *et al*. propose a novel approach for large-scale irrigation systems and aqua farms using a single-phase electric grid-fed three-phase induction motor drive integrated with photovoltaic and battery storage [3]. Their study employs TS-fuzzy based direct torque control to achieve robust control during load changes, enhancing system reliability and operational efficiency.

Kumar *et al.* introduce a four-level inverter fed open-end winding induction motor drive for sugarcane shredding machines in the sugar industry [7]. Their research addresses drawbacks of existing two-level inverters, focusing on reducing harmonic distortions and enhancing efficiency through experimental validation and simulation using MATLAB/Simulink.

Chirdchoo *et al*. propose an innovative IoT-based power electronics solution for shrimp farms, integrating a three-level half-bridge DC-DC converter with zero voltage and zero current switching [8]. Their study demonstrates efficient DC bus voltage management for a VFD inverter, achieving high operational efficiency and reliability under varying conditions.

Das *et al*. present a speed sensor-less stator flux-oriented vector control strategy for dual-stator induction generators in grid-tied wind energy systems [9]. Their approach eliminates the need for speed encoders, reducing costs and errors while enhancing performance through simulation and experimental validation using ds PACE hardware.

Patel *et al*. provide a detailed analysis of various converter topologies used in Variable Frequency Drives (VFDs) for AC motors, focusing on power electronics modulators and their impact on grid stability [10]. Their study evaluates line current Total Harmonic Distortion (THD) to compare efficiency and operational limitations of different VFD converter designs.

Ghosh *et al*. propose an advanced Direct Torque Control (DTC) strategy for induction motor drives (IMDs) using a Four Switch Voltage Source Inverter (FSTPI) [4]. Their research enhances dynamic performance through space vector modulation and intelligent control algorithms, achieving superior torque ripple reduction and speed regulation compared to traditional methods.

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OBJECTIVES

The main objective of the thesis work is as follows.

- To develop a model or models to implement V/F control of an induction motor.
- Development of new optimization algorithm adaptive bee colony optimization algorithm for tuning of the Proportional Integral (PID) controller to achieve optimum speed control for induction motor.
- Study the speed torque waveforms for stability under various modes of operation, when the motor speed is constant, accelerating or decelerating.
- Compare the outcomes from the two algorithms namely V/F control and proposed controller at different speed durations.

METHODOLOGY

The model was created in a SIMULINK/MATLAB setting. Control flow statements, functions, data structures, input/output, and object-oriented programming capabilities are all included in this high-level matrix/array language. Its salient characteristics are as follows:

- High-level programming language for engineering and scientific computing.
- Apps for curve fitting, data classification, signal analysis, control system tuning, and many other tasks.
- Graphics for displaying data and tools for producing custom plots.
- Desktop environment tailored for iterative exploration, design, and problem-solving.

Motor Modelling and Simulation

Asynchronous machines are currently the most widely used electrical machines, primarily serving as induction motors and occasionally as generators. When the stator windings are connected to a balanced three-phase network, they produce a rotating magnetic field due to current flowing through the coils. This field rotates at a rate that is in sync with the electrical source's frequency that is attached to the stator. One cycle of the alternating current (AC) is represented by each rotation of the magnetic field, which produces a pair of poles (N, S) on the stator surface. The quantity of pole pairs (P) in this situation is equal to Electromagnetic current.

Control system designing for motor in MATLAB

V/F Motor Control System

In this control method, the motor receives variable frequency signals generated by PWM control from an inverter. The V/f ratio is kept constant to maintain consistent torque across the entire operating range. This approach, known as "scalar control", regulates only the magnitudes of frequency and voltage inputs. It is favored for its simplicity and cost-effectiveness, requiring minimal motor knowledge for frequency adjustment, thus widely adopted. However, scalar control has drawbacks. The torque developed is influenced by the load because it is not directly controlled. Additionally, the inverter's predefined switching pattern limits the control's transient response speed. Continuous blockage of the rotor can cause motor heating, despite implementing overcurrent control. Integrating a speed or position sensor can mitigate these issues but adds complexity, size, and cost to the system. Various methods exist for implementing scalar control.

PI adaptive Bee Colony Optimization for Induction Motor (ABCO_IM)

ABCO_IM is inspired by the foraging behavior of honeybee swarms. Working flowchart of Adaptive Bee Colony Optimization for MOTOR (ABCO_IM) is shown in Figure 5.

It iteratively improves candidate solutions by simulating the exploration and exploitation of food sources. Circuit model of a single-phase inverter is shown in Figure 6. ABCO_IM can optimize the

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parameters of the induction motor ring circuit by optimizing the PI parameters, particularly in cases where the solution space is constrained or dynamic. Generation of pulses in the control is shown in Figure 7.

Controller Circuit Designing and PWM for induction motor

Principle of Sinusoidal PWM

Figure 6 Depicts the circuit model of a three-phase PWM inverter, while Figure 8 illustrates the waveforms of the carrier wave signal V_{tri} and the control signal $V_{control}$. Three-phase PWM Inverter of general three-phase sine-PWM inverter is shown in Figure 8. The inverter outputs include line-to-neutral voltages V_{A0}, V_{B0}, V_{C0} and line-to-line voltages V_{AB}, V_{BC}, V_{CA} respectively. Reference signal generation for PWM is shown in Figure 9, and MATLAB/SIMULINK designing of three phase converters is shown in Figure 10.

RESULT AND DISCUSSION

The primary goal of this project is to develop a model or models for implementing V/f control on an induction motor. This requires a thorough understanding of the PWM (Pulse Width Modulation) Inverter, which powers the induction motor. The project involves studying and simulating PWM signal generation and various inverter topologies. The analyses are based on MATLAB simulations that depict different operating speeds of the induction motor, utilizing a model built from a set of standard equations and values covering current, voltage, power, efficiency, and speed.

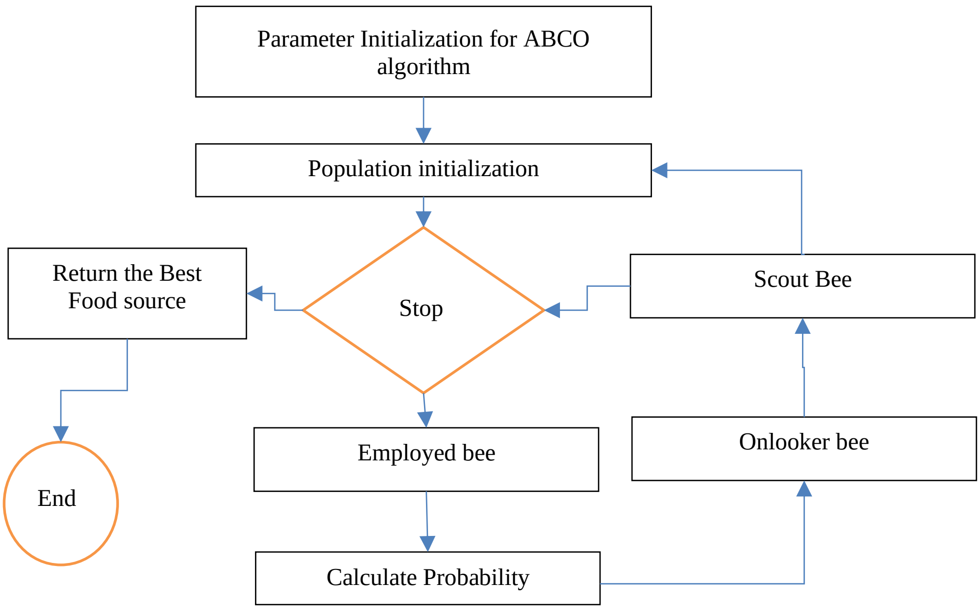

Figure 5. Adaptive Bee Colony Optimization for MOTOR (ABCO_IM) working flowchart.

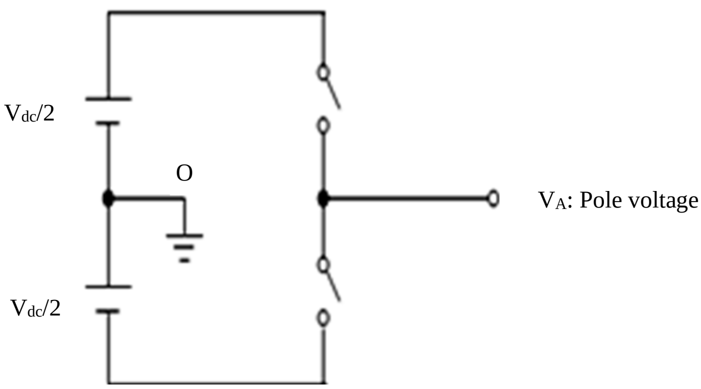

Figure 6. Circuit model of a single-phase inverter.

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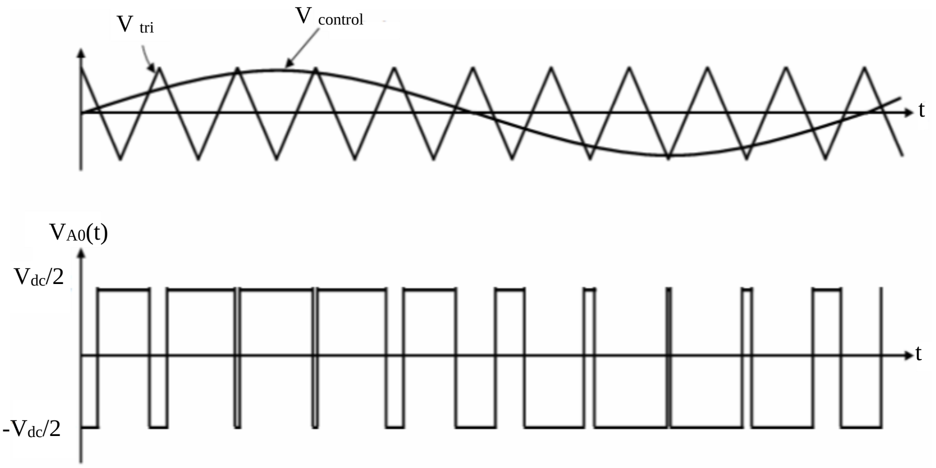

Figure 7. Generation of pulses in the control.

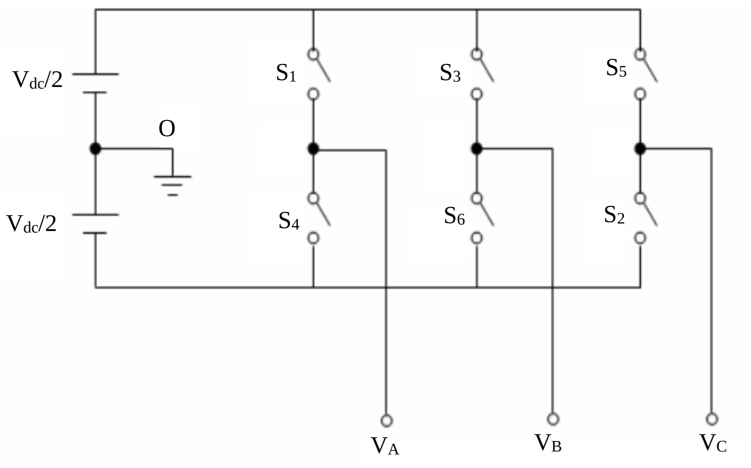

Figure 8. Three-phase PWM Inverter of general three-phase sine-PWM inverter.

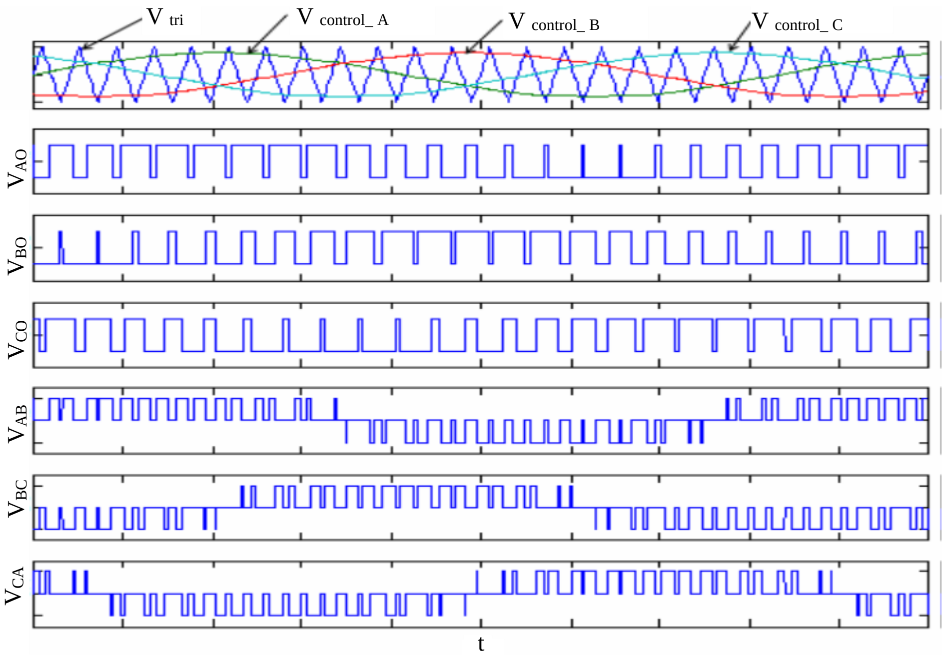

Figure 9. Reference signal generation for PWM.

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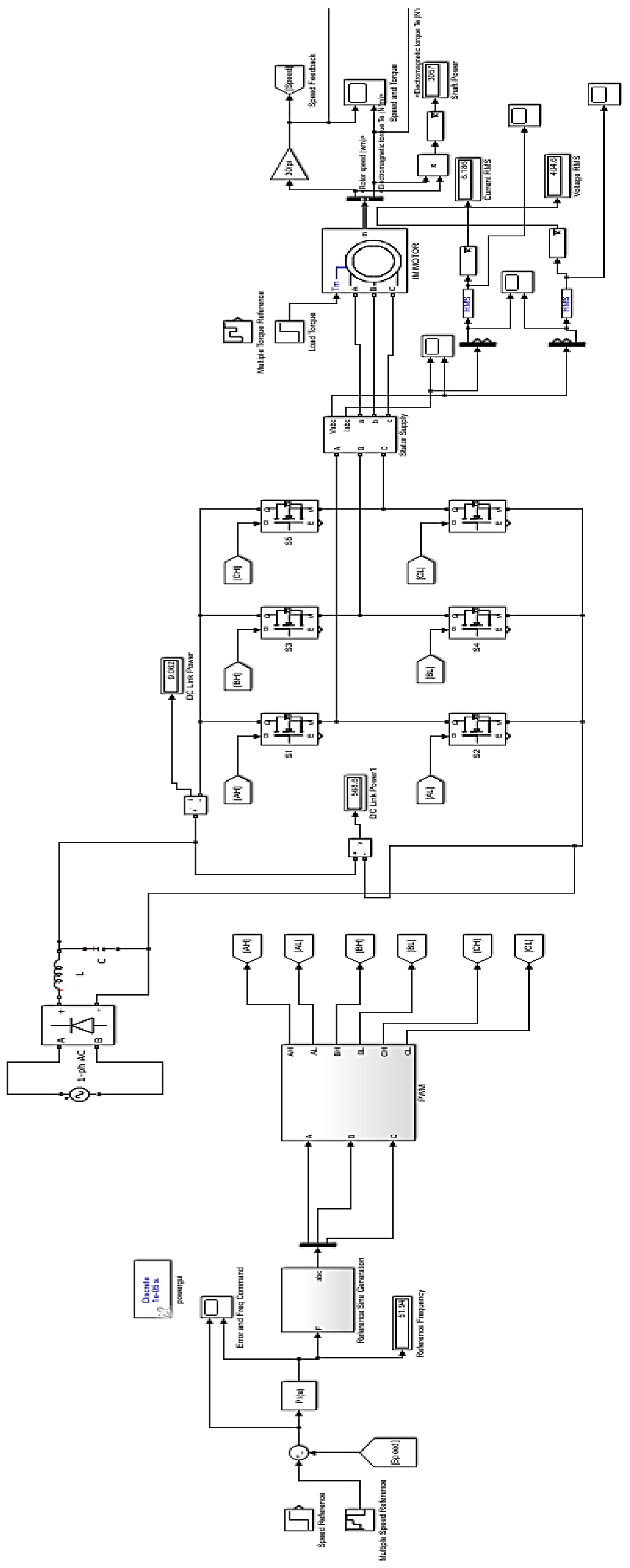

Figure 10. MATLAB/SIMULINK designing of three phase converters.

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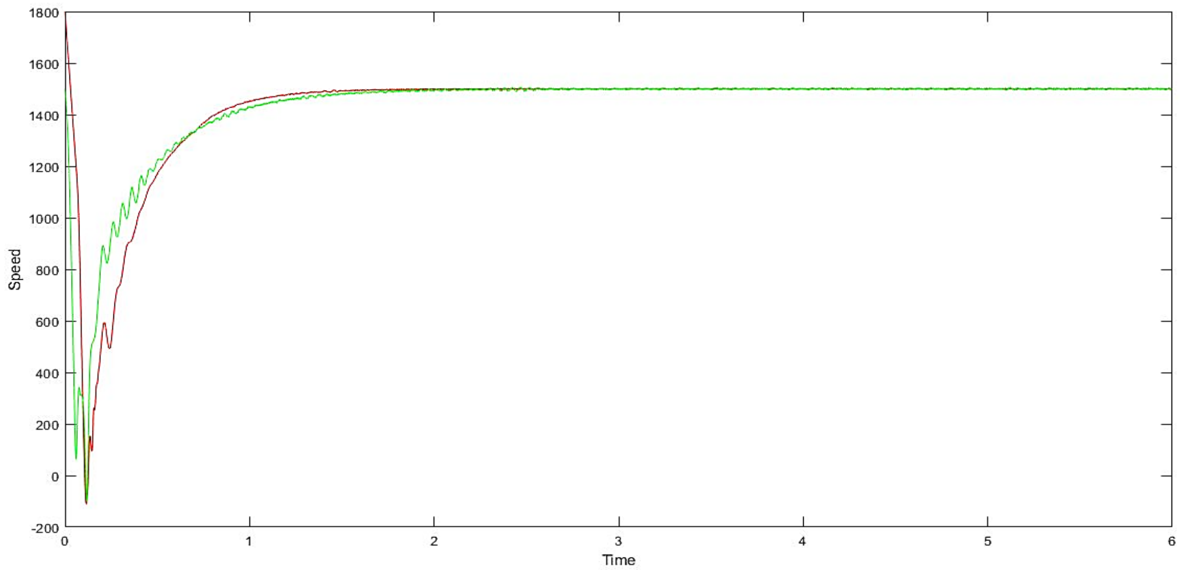

Figure 11. Comparative analysis of speed in the two systems in case 1 (constant drive).

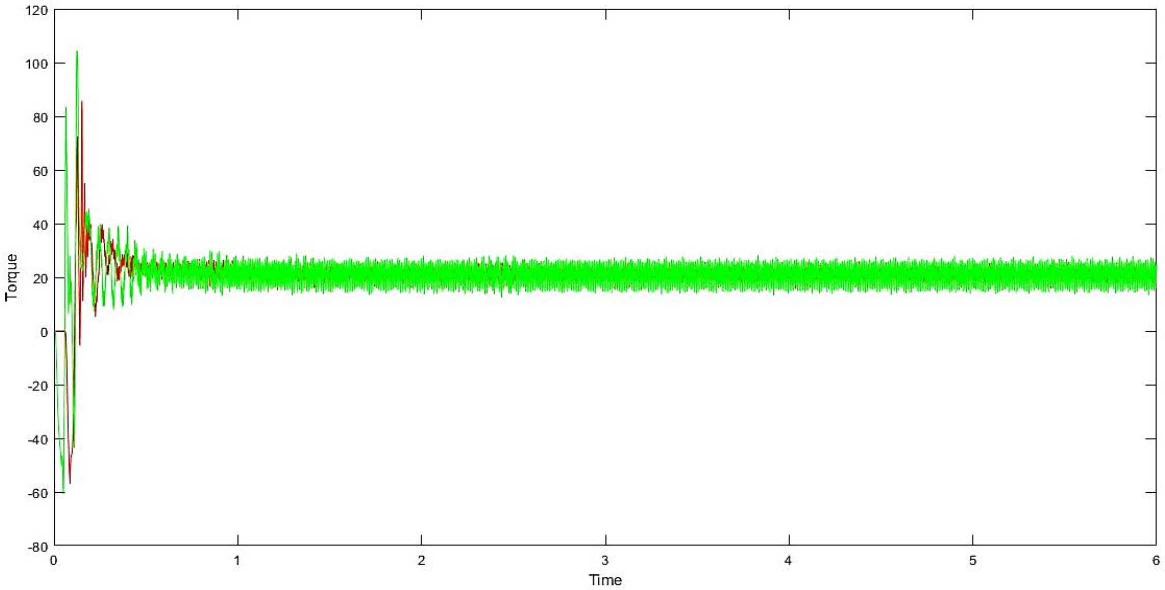

Figure 12. Comparative analysis of torque in the two systems in case 1 (constant drive).

The work explores two systems: one controlled by traditional PI (Proportional-Integral) regulatory mechanisms, and another that incorporates adjustments to waveform disturbances through ABCO_IM (Artificial Bee Colony Optimization for Induction Motors) algorithm.

Case 1: Analysis of the control system with variation in speed (acceleration) at 3 sec. The control system analysis at with variation (acceleration) at 3 sec and shown in the Figures 11–14.

Case 2: Analysis of the control system with variation in speed (deceleration) at 3 sec, shown in Figures 15–18.

Case 3: Analysis of the control system at constant speed (Figures 19–22).

The speed and torque waveforms are being discussed in the following four cases with three modes of operation, acceleration, constant drive and deceleration as shown in Figures 19–22.

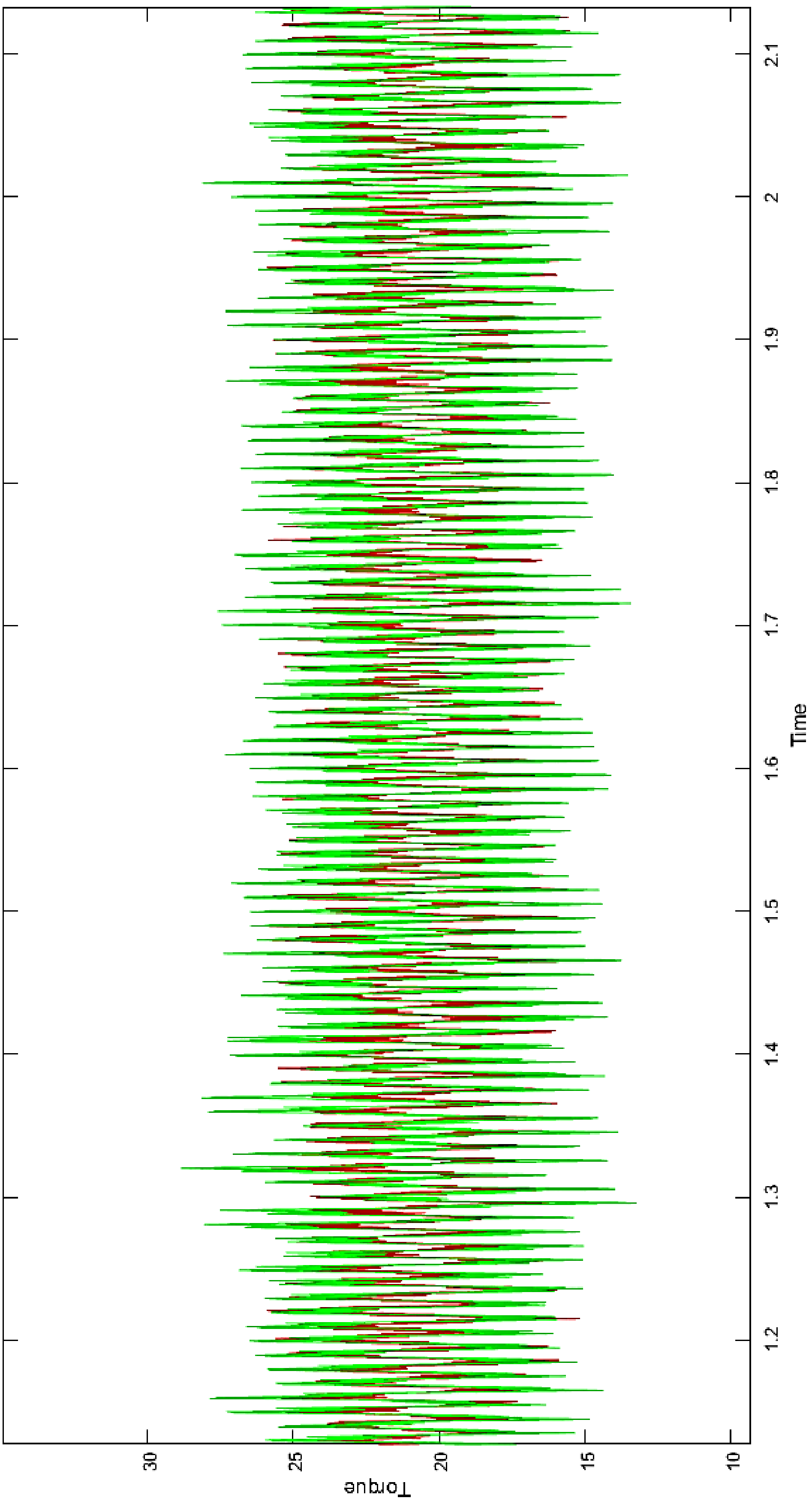

Figure 13. Close view of the torques in two systems in case 1 (constant drive).

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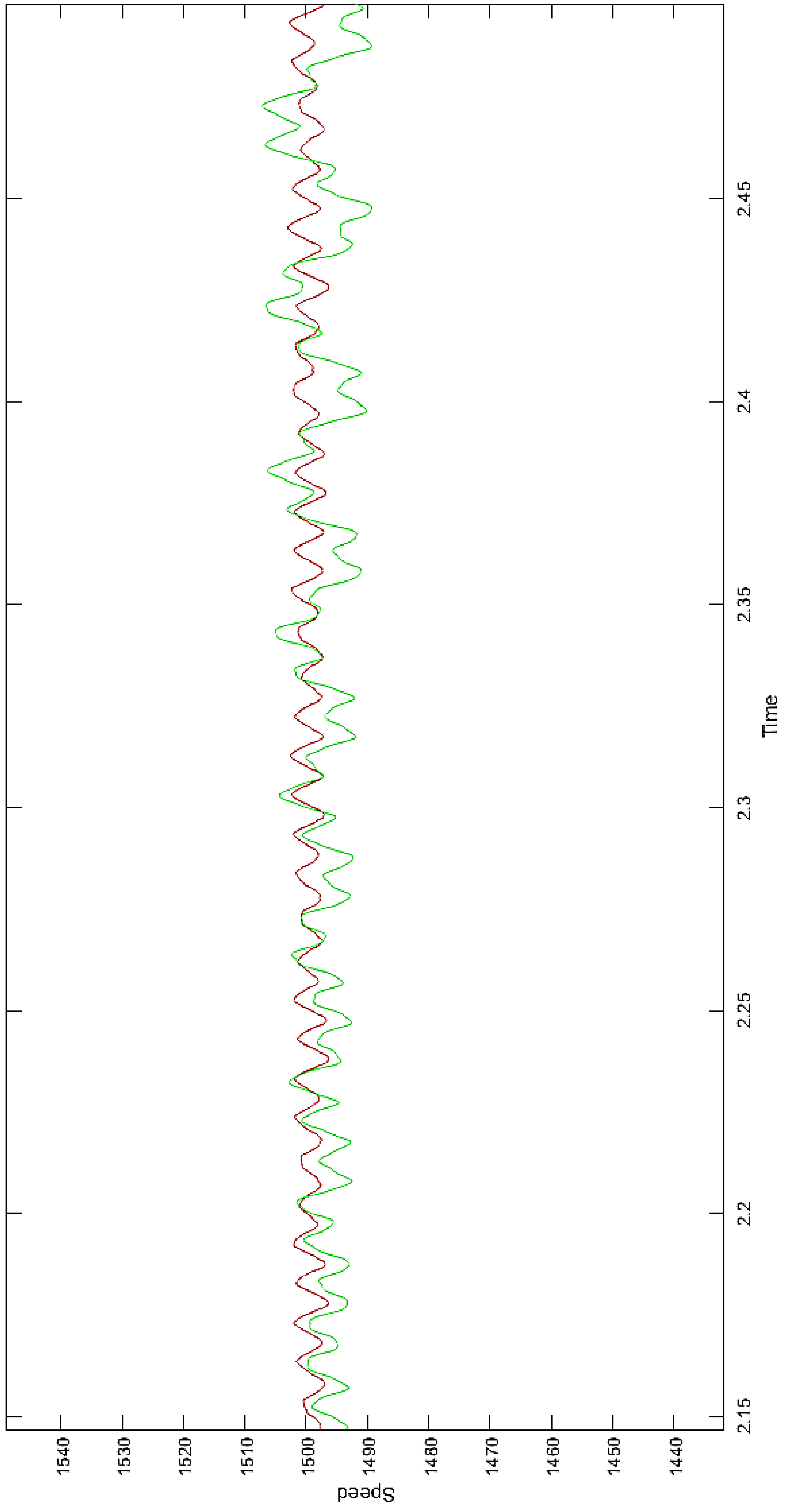

Figure 14. Close view of the speeds in two systems in case 1 (constant drive).

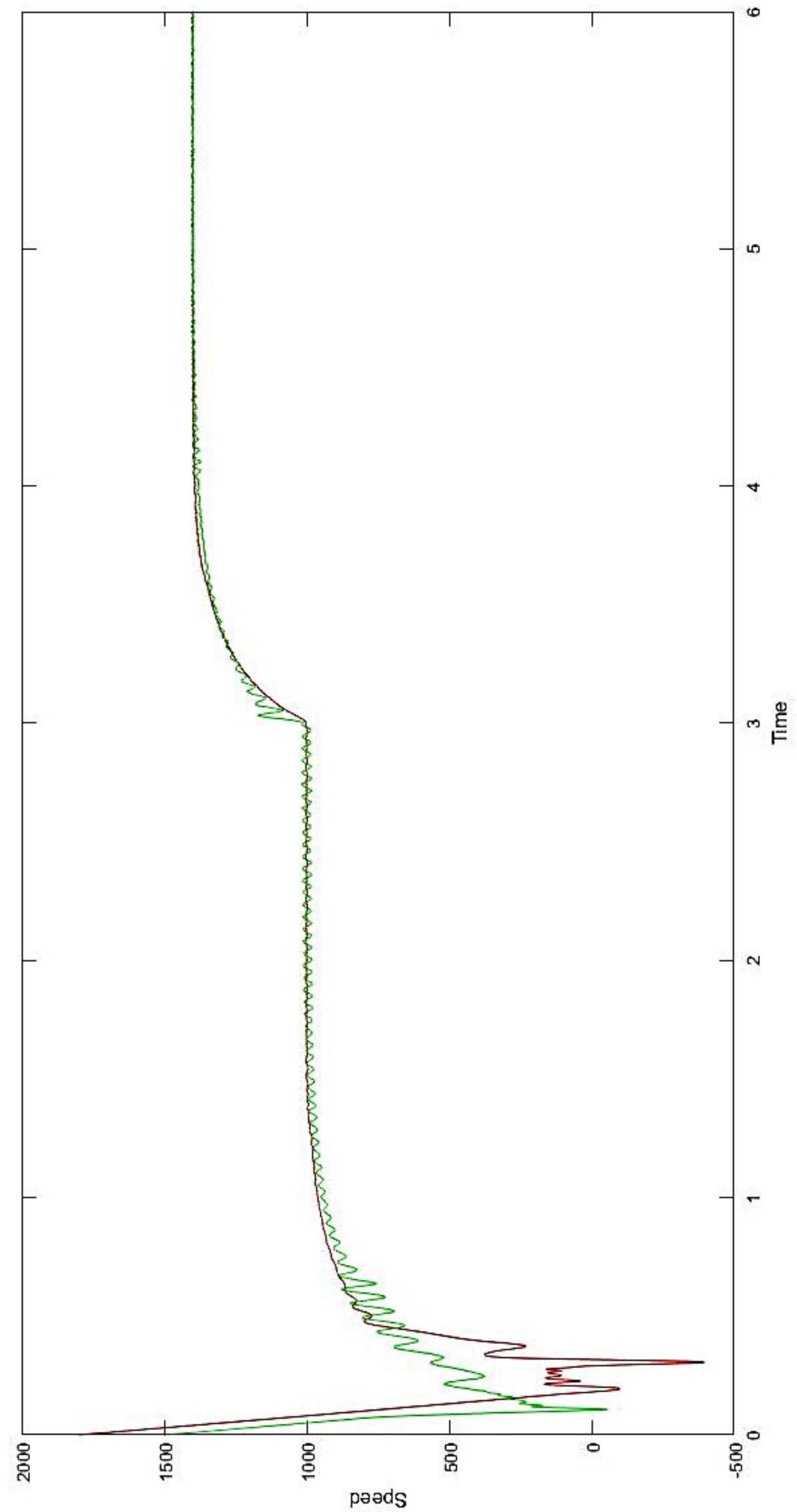

Figure 15. Comparative analysis of speeds in the two systems in case 2 (acceleration mode).

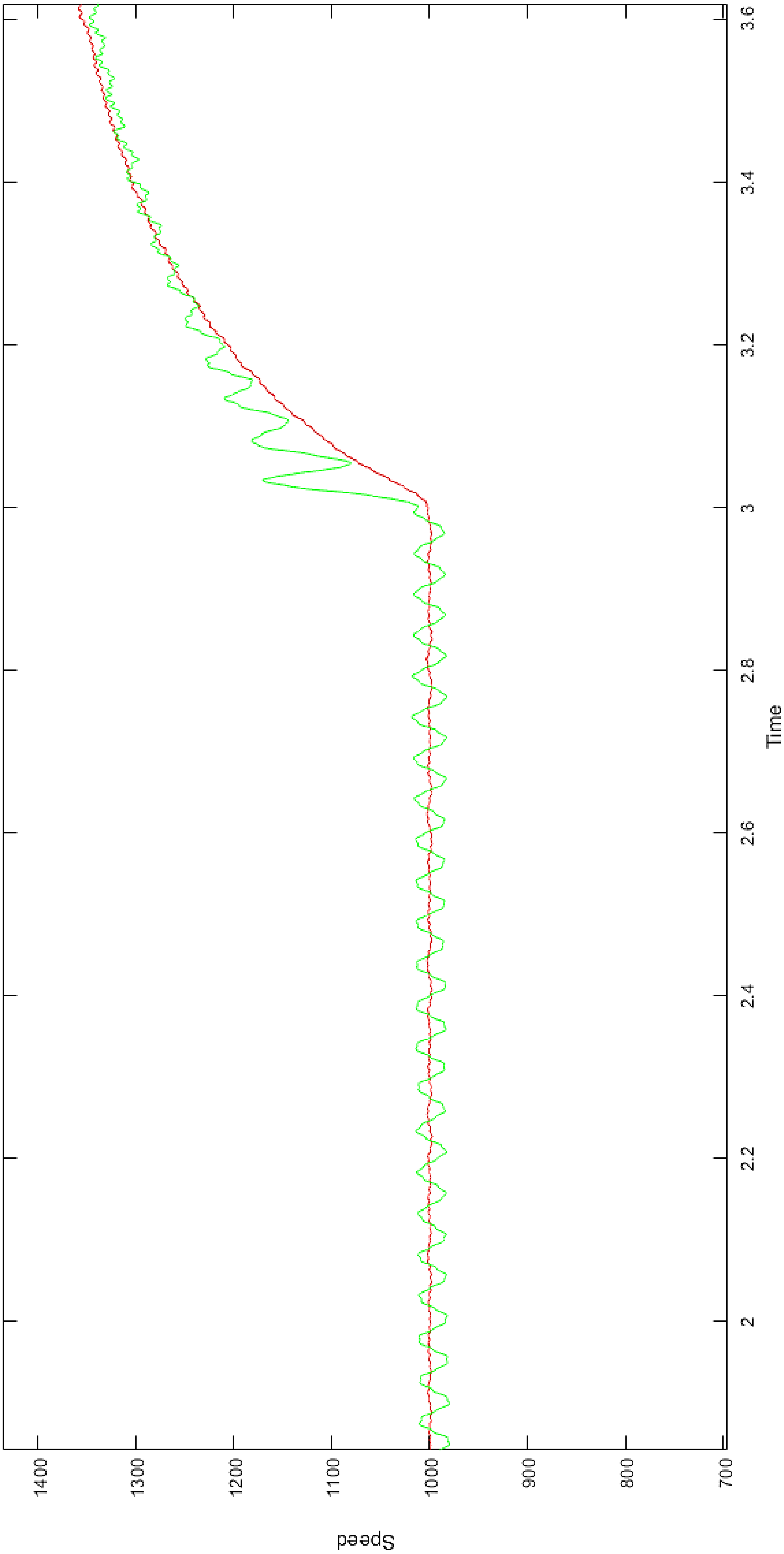

Figure 16. Close view of the speeds in two systems in case 2 (acceleration mode).

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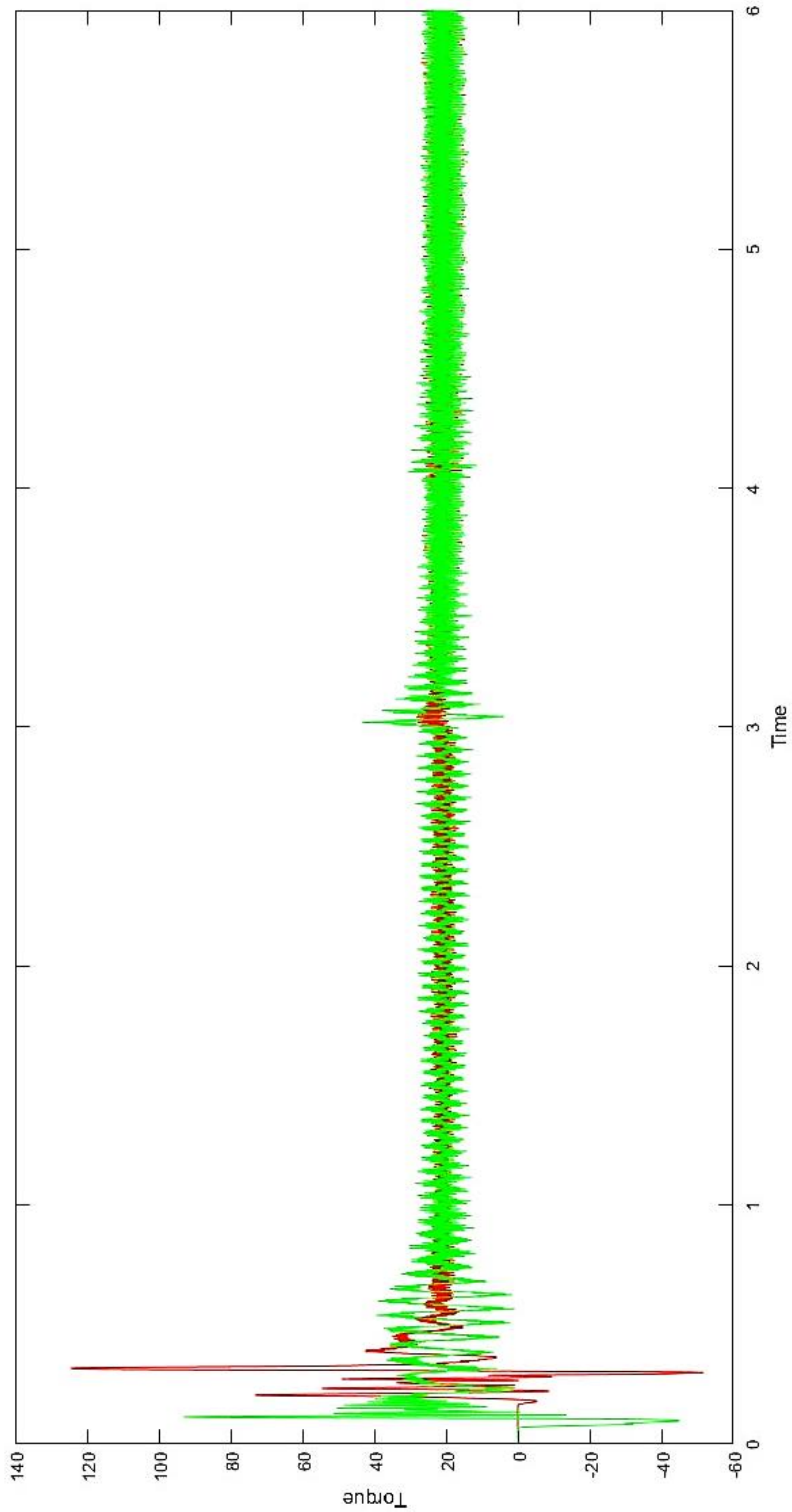

Figure 17. Comparative analysis of torque in the two systems in case 2 (acceleration mode).

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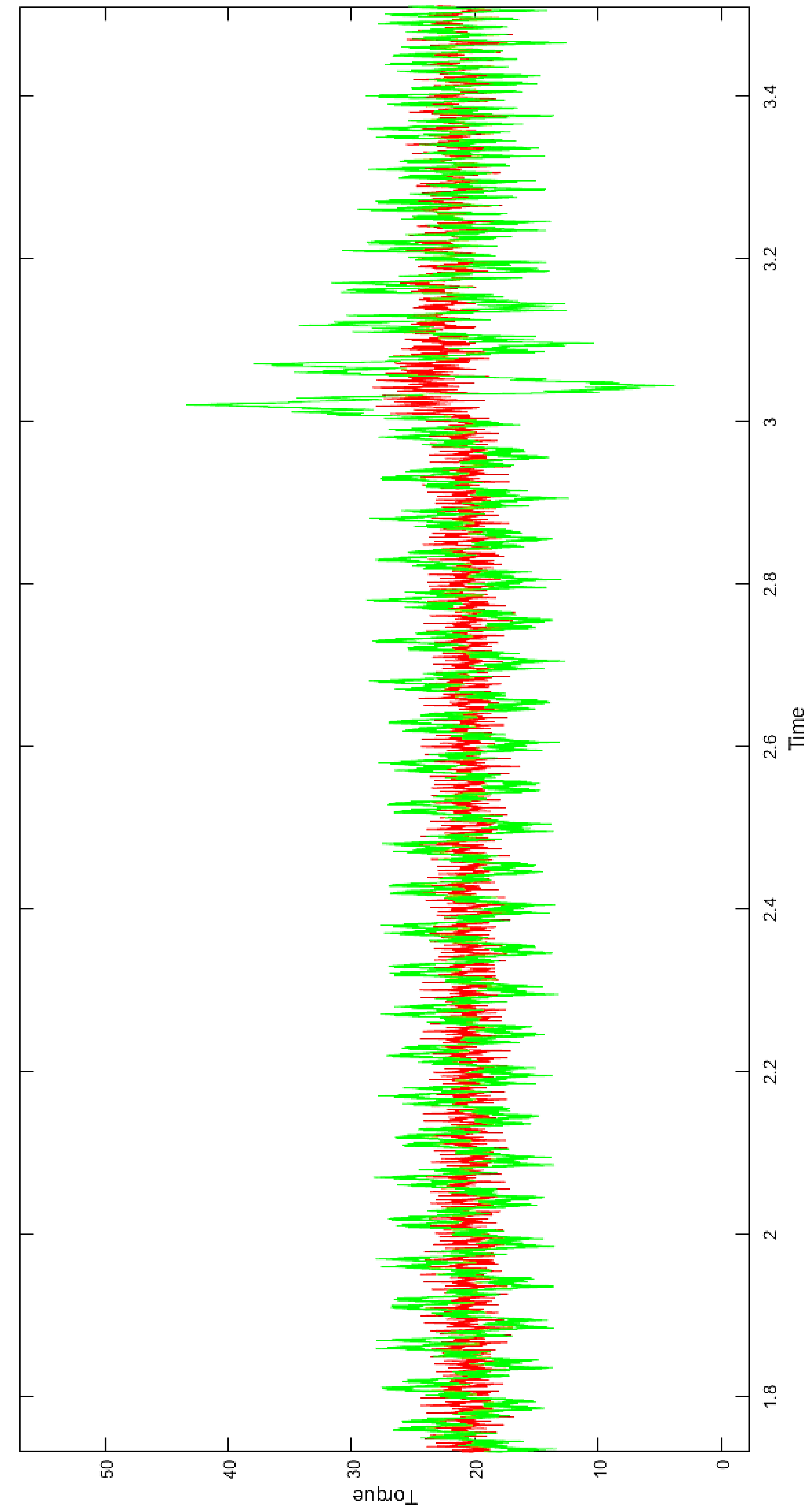

Figure 18. Close view of the torque in two systems in case 2 (acceleration mode).

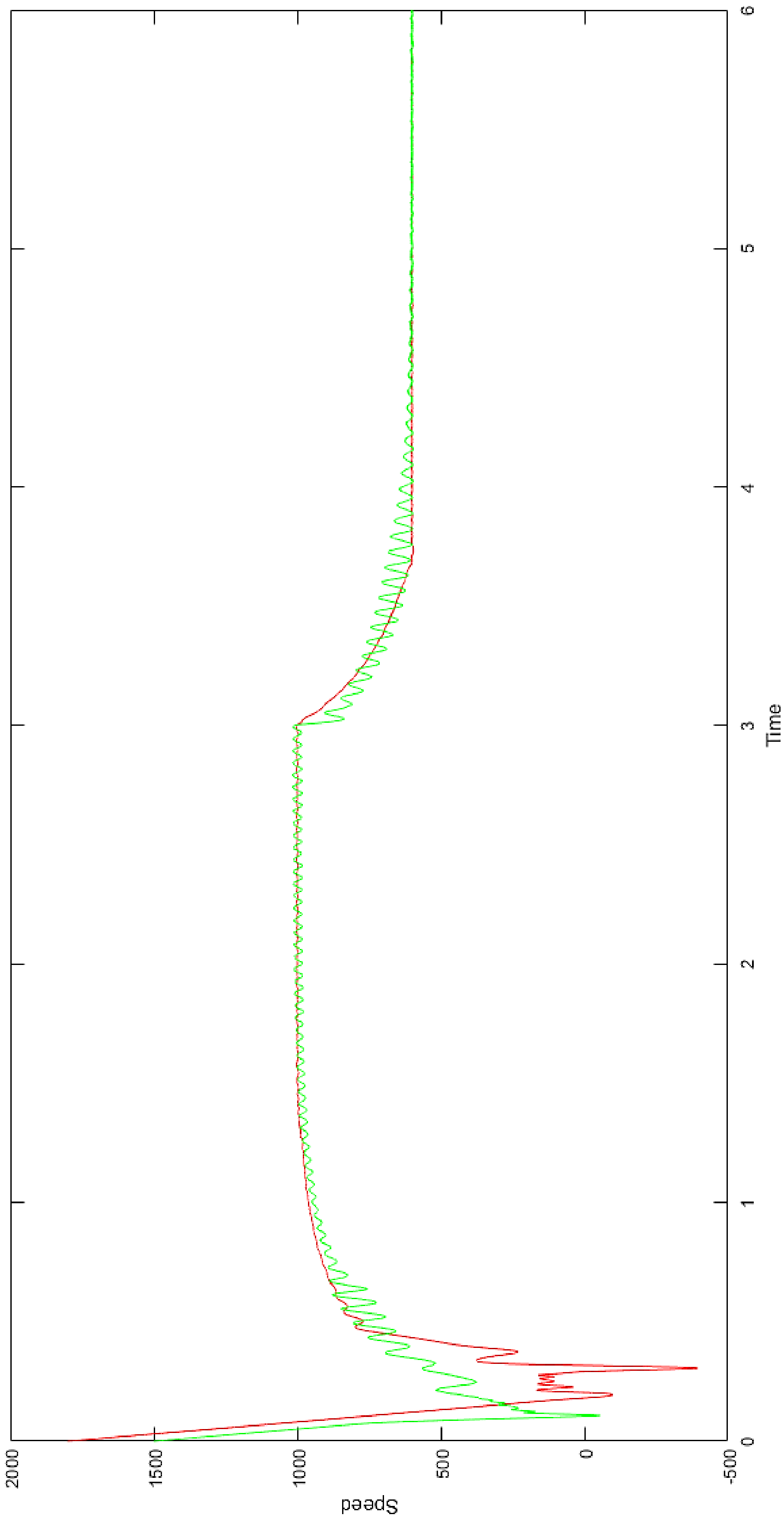

Figure 19. Comparative analysis of speeds in the two systems in case 3 (Deceleration mode).

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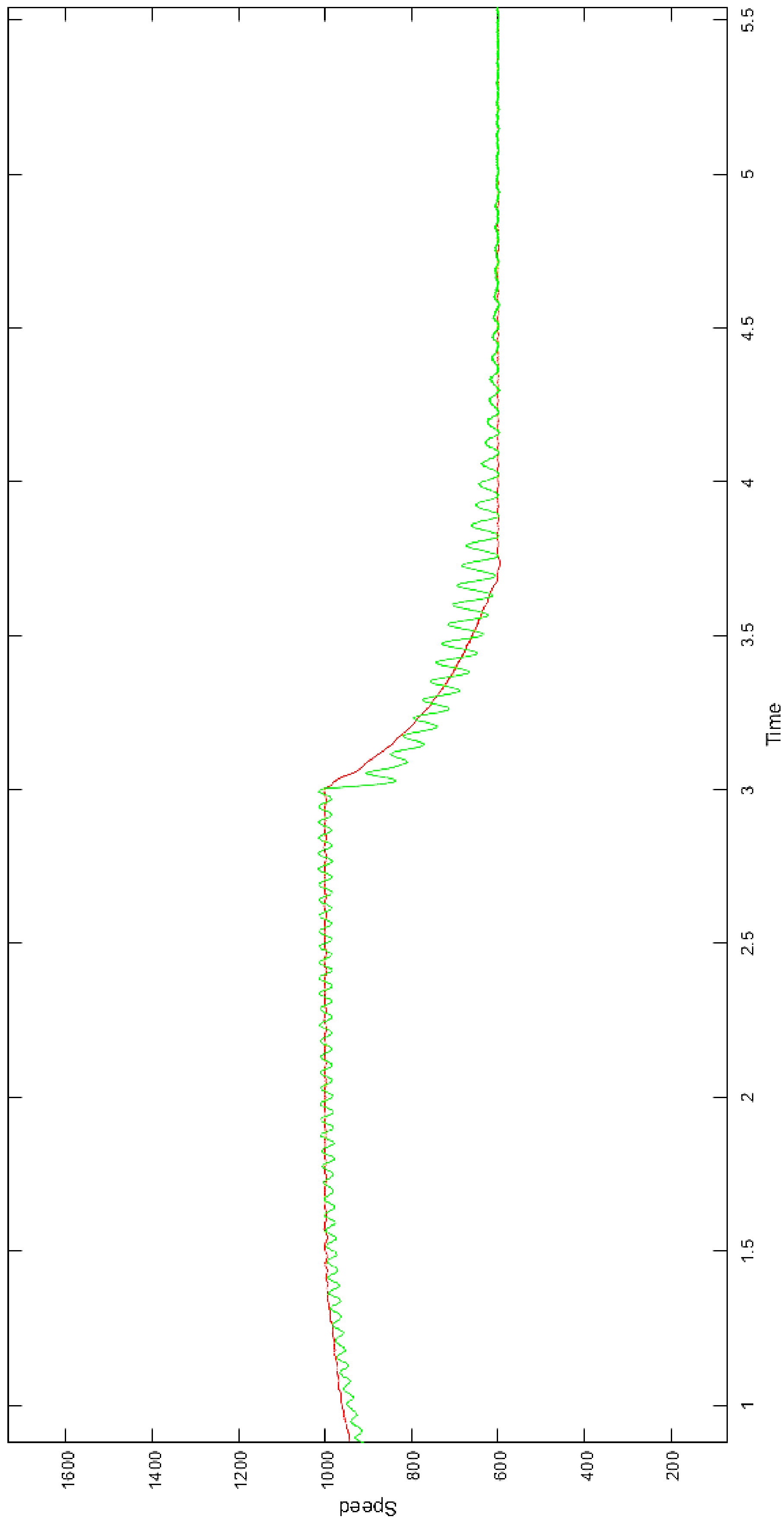

Figure 20. Close view of the speeds in two systems in case 3 (Deceleration mode).

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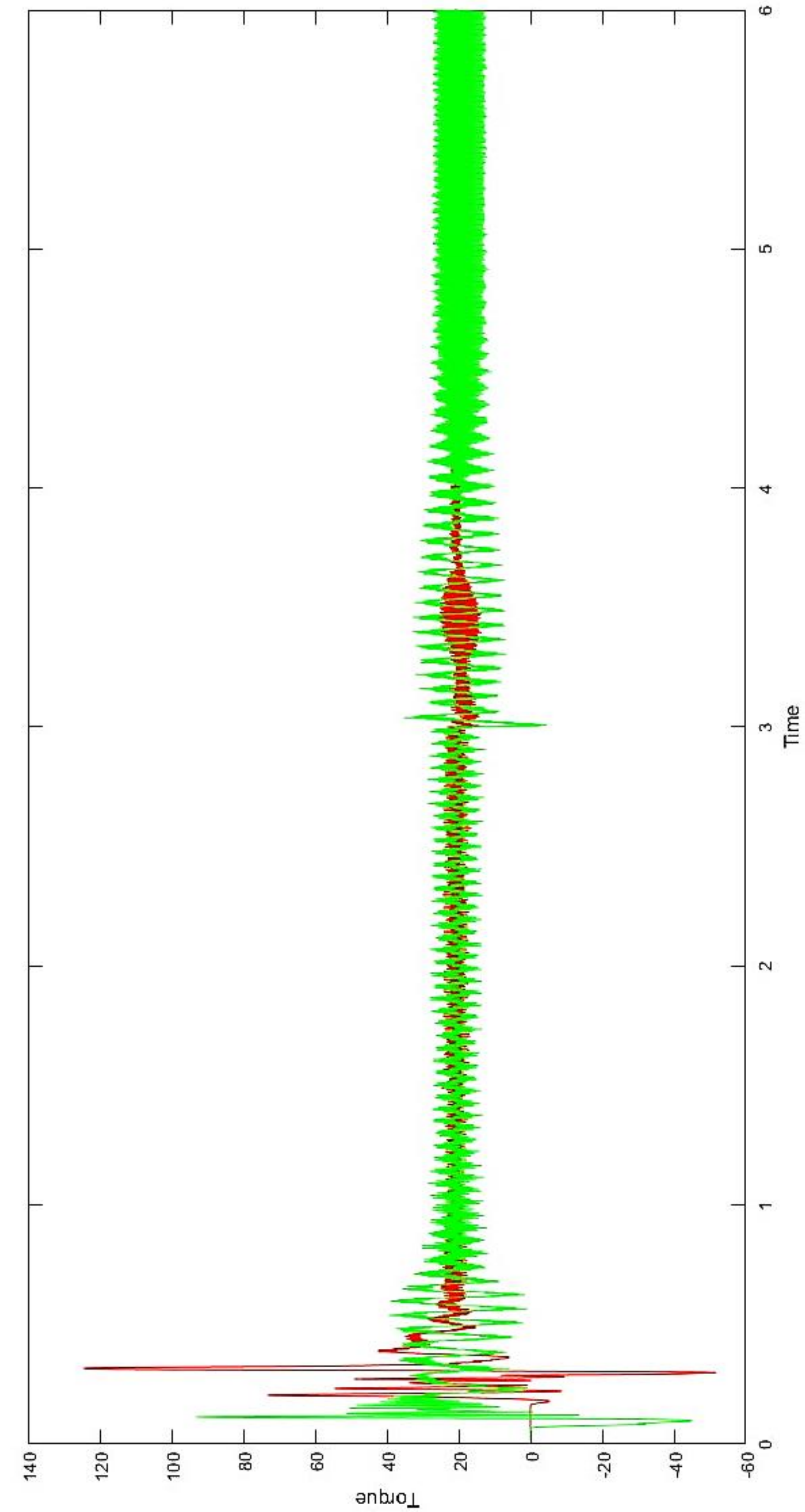

Figure 21. Comparative analysis of torques in the two systems in case 3 (Deceleration mode).

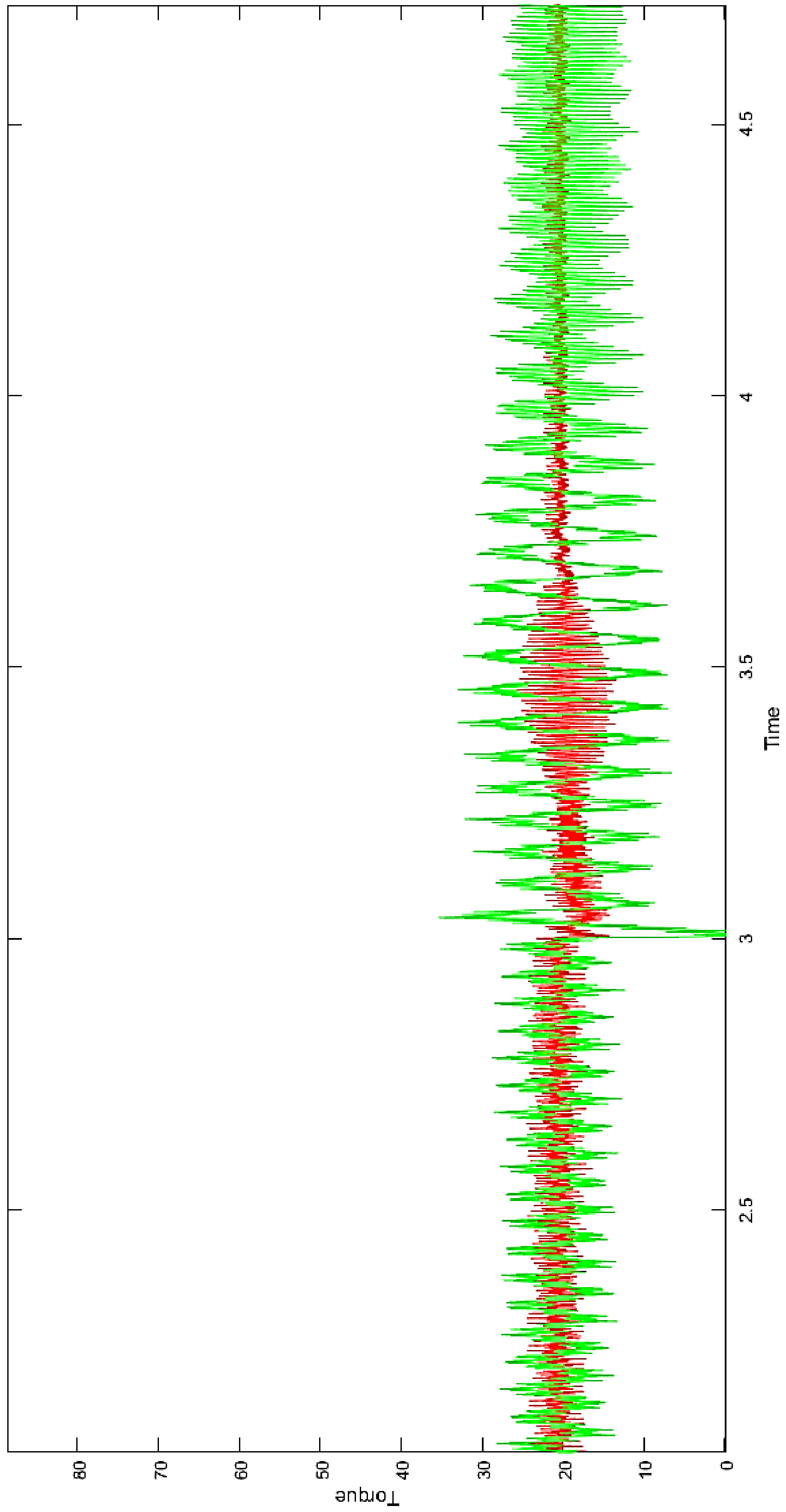

Figure 22. Close view of the torque in two systems in case 3 (Deceleration mode).

CONCLUSION

This research highlights significant advancements in optimizing V/F control strategies for asynchronous motors using the Adaptive Bee Colony Optimization algorithm. By integrating this algorithm into the PID controller tuning process, the study demonstrates enhanced motor performance in terms of speed control and stability under dynamic operational conditions. MATLAB/Simulink simulations validate the efficacy of the proposed approach, indicating its potential for improving industrial motor efficiency while minimizing operational complexities. Future research directions may explore further enhancements in control algorithms and their integration with advanced sensor technologies to achieve even higher levels of motor performance and reliability in industrial settings.

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