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A Robust Frequency-Domain-Based Order Reduction Scheme for Linear Time-Invariant Systems

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ABSTRACT This paper presents a robust model order reduction technique with guaranteed stability, minimum phase, and matched steady-state response for linear time-invariant single-input-single-output systems. The proposed approach is generalized, allowing the designer to select any desired order of the reduced-order model (ROM). In contrast to the published literature, which primarily uses the time-domain behavior, the proposed technique utilizes the frequency-domain information of the full-order system. The suggested strategy allows the determination of the optimal ROM in a single step, simpler than the various recently reported mixed methods. The robustness is demonstrated using convergence studies and statistical measures about the final solution quality and model coefficients. The superiority over the recent literature is illustrated through four numerical examples using various time-domain and frequency response performance metrics.

INDEX TERMS Frequency response, linear time-invariant system, model order reduction, reduced-order modelling, single-input-single-output system.

I. INTRODUCTION

Model order reduction (MOR) deals with the approximation of complex, high-order models with the low-order ones [1]. A reduced-order model (ROM) requires fewer variables and parameters for representation either in transfer function or state-space form while preserving the essential characteristics of the original system.

The transfer function of a generalized full-order (original) linear time-invariant (LTI) single-input-single-output (SISO) system is given by (1):

$$G_O(s) = \frac{a_m s^m + a_{m-1} s^{m-1} + \cdots + a_1 s + a_0}{s^n + b_{n-1} s^{n-1} + \cdots + b_1 s + b_0}, \quad (1)$$

where a_k $(k = 0, 1, \ldots, m)$ and b_k $(k = 0, 1, \ldots, n-1)$ are the coefficients of the numerator and denominator, respectively, of $G_O(s)$; m and n are integers; and $m \leq n$.

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The transfer function of a ROM can be defined by (2):

$$G_R(s) = \frac{N_R(s)}{D_R(s)} = \frac{A_M s^M + A_{M-1} s^{M-1} + \cdots + A_0}{s^N + B_{N-1} s^{N-1} + \cdots + B_0}, \quad (2)$$

where A_k $(k = 0, 1, \ldots, M)$ and B_k $(k = 0, 1, \ldots, N-1)$ are the coefficients of the numerator and denominator polynomials, respectively, of $G_R(s)$; M and N are integers; $M < m$, and $N < n$.

ROM helps alleviate the computational burden during process control simulation studies, reduces simulation time during numerical analysis of dynamical systems, and reduces hardware overhead for practical implementation. Research in the field of MOR has remained vigorously active in the past decade with applications reported in various fields of science and engineering, such as semiconductor components packaging [2], electromagnetism [3], etc.

MOR strategies for LTI SISO systems, such as the step and impulse inputs based response matching [4], mixed positive-bounded balanced truncation [5], and the balanced realization technique (BRT) [6], have been reported in the