Contents lists available at ScienceDirect

Sustainable Energy, Grids and Networks

journal homepage: www.elsevier.com/locate/segan

Deep learning assisted surrogate modeling of large-scale power grids

Asif Hamid [a], Danish Rafiq [a,*], Shahkar Ahmad Nahvi [a], Mohammad Abid Bazaz [b]

[a] Department of Electrical Engineering, Islamic University of Science and Technology, Awantipora, 192122, Jammu & Kashmir, India
[b] Department of Electrical Engineering, National Institute of Technology, Srinagar, 190006, Jammu & Kashmir, India

ARTICLE INFO

Article history:
Received 12 August 2022
Received in revised form 29 January 2023
Accepted 13 March 2023
Available online 16 March 2023

Keywords:
Dynamic equivalencing
MIMO systems
Deep learning

ABSTRACT

The model order reduction (MOR) enterprise has shown unprecedented applications in the area of power systems by allowing tractable and realistic simulations of complex power grids. Nearly all model reduction techniques rely on constructing a linear reduced trial subspace followed by a *Galerkin* projection to restrict the evolution of the latent dynamics onto the reduced subspace. However, power system models often exhibit a slow decay of singular values and, as such, are often approximated poorly due to the truncation of higher-order modes. Furthermore, employing a linear projection for such models places a fundamental limit on the accuracy of the reduced order models (ROMs). This paper uses techniques from machine learning to develop a dimensionality reduction framework for large-scale power grid models to overcome these limitations effectively. In particular, we use autoencoder (AE) network to learn low-dimensional nonlinear trial manifold to avoid the limitation of a linear trial subspace. This is followed by the use of long short-time memory (LSTM) networks to obtain the evolution of the reduced dynamics in a non-intrusive manner. The resulting framework yields ROMs that are compact and are several orders of magnitude more accurate than the linear projection-based methods. We demonstrate the proposed technique on the standard IEEE 118-Bus system, which has 54 generators, and the European high-voltage system with 260 generators.

1. Introduction

Power grids are the backbone of modern industries. The analysis, protection, and emergency control of the national and international grids are the most critical aspects of the power utility. To ensure a reliable operation of power grids, the power system operation companies depend on fast and accurate dynamic simulations to train operators, analyze large sets of scenarios, assess the dynamic security in real-time, or schedule the day-ahead operation [1]. However, these tasks are becoming computationally more intensive due to the increasing size and complexity of modern power systems. The size of a power system is usually measured in terms of the number of buses and branches. A typical power grid consists of thousands of interconnected buses and hundreds of generators, resulting in mathematical models that are high-dimensional and numerically expensive to simulate [2]. Apart from being large-scale, power systems have dynamics that are strongly nonlinear and span multiple time scales in the mechanical and electrical domains [3]. The high penetration of distributed generation using renewable sources such as solar photovoltaic, wind and battery storage, on the other hand, have further increased the model complexity in analysis, simulation and control [4]. This current trend in grid modernization via inverter-based technologies are resulting in highly interconnected and complex power systems than ever before. The growing complexity and large degree of freedom results in a huge computational bottleneck that preclude the use of such models in real-time applications such as transient stability assessment, trajectory sensitivity analysis, dynamic security assessment, online system identification, and fault detection [2]. Though computing power technologies have advanced over the last decade, allowing for faster dynamic simulations, unfortunately, the scale and complexity of simulations have also grown simultaneously. The increased demand for more detailed and complex power system models (distributed energy sources, power-electronic interfaces, active distribution networks, etc.) can easily push any given computer to its limits [1]. Since for real-time power system analysis, there is a limitation on the scale of the system to be simulated, it becomes mandatory to develop surrogate or reduced models that preserve the desired dynamic properties of the original system. These simplified models (*dynamic equivalents*) can therefore be readily used to replace the true high-fidelity full order models (FOMs) for computational intensive applications [5]. The most common and widely adopted strategy to obtain reduced models is to employ the so-called *projection* techniques. These techniques typically comprise two stages: an *offline* stage and an *online* stage. During the offline stage, these methods perform computationally

* Corresponding author.
E-mail address: danish.rafiq@iust.ac.in (D. Rafiq).

https://doi.org/10.1016/j.segan.2023.101031
2352-4677/