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Application of Various Order Reduction Methodologies Over Power System Components

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Abstract: Study and analysis of highly interconnected electrical system is time consuming and difficult; and appearance of inner uncertainty, result in system complexity with higher order, posing a great challenge to both system analysts and control engineers. Simplification of such design to their lower order equivalent via order reduction accomplishes a good approximation to the system for analysis. This paper attempts to discuss few noteworthy approximation techniques relevant to power system components. The test result based on the error computation between the original and reduced systems through the varied algorithms validate the models obtained to be a good approximant.

Keywords: Power system design, uncertain system, order reduction, direct truncation, gamma-delta approximation, differentiation.

1. INTRODUCTION

Electrical power system is efficiently modelled and analyzed by classification of key elements and eradication of spurious one. Some of the basic power system modules are supplies, loads, conductors, capacitors, reactors, protective devices and SCADA systems. All together, they result in a very high order of state variables for simulation, trajectory sensitivity analysis, control and others making their overall investigation cumbersome. Here, develop a loophole for control engineers to implement an optimal control strategy for such problem to forbid the computational burden, maintaining the accuracy and dynamic behaviour of the original system. At this juncture, application of model order reduction is inevitable to reduce computational effort and process time with an aim of deriving an approximate reduced model. Order reduction is an important tool in power system to deal with size and complexity, since it provides a simplified representation of the system, while preserving the dynamic characteristics of interest. A bulk of model reduction techniques in power system are tailored for controller design and transient/small signal stability analysis, both in time domain as well as in frequency domain [Troullinos, Dorsey, Wong, and Myers, (1988); Martins, Lima, and Pinto, (1996); Gustavsen, and Semlyen, (1999); Noda, Semlyen, and Iravani, (2003); Chaniotis, and Pai, (2005), Sambariya, and Prasad, (2012)].

Parametric uncertainty in real system is an unavoidable case and must be considered because of nonlinear effects, environmental conditions, tolerance of the equipments, measurement faults and many others. Uncertain or interval system is an emerging field of research from the day of its discovery. They are defined as the system varying within a finite range instead of being deterministic. This set the motive of the paper, to deal with higher order system of uncertain nature. The uncertainties in the plant representation are demonstrated via an interval bound for each numerator and denominator polynomial coefficients. Order reduction of such systems also grabbed the interest for investigation; justified by the methodologies available notably Routh Approximation Method, Pade Approximation methods and others [Ismail, Bandyopadhyay, and Gorez, (1997); Bandyopadhyay, Upadhye, and Ismail, (1997); Choudhary, and Nagar, (2013 a, b)].

With an aim to propose relevant methodologies for power system components of uncertain form, the paper is stretched over seven sections; introduction to power system design with a review of reduction techniques applied above them in section 1 followed by the description of a block diagram of physically available power system design in section 2. This section states the components of interest to apply order reduction algorithm. Section 3 accommodates the representation of higher and lower order system with an illustration to the reduction methodologies of interest namely direct truncation (*DT*); gamma-delta approximation (*GD*) and differentiation method (*DM*). This section also state the validation tool used for assessment of the algorithms. Section 4 present an example taken from the available literatures to show the algorithms supremacy. In section 5, these algorithms are applied on the components of interest considered from power system design. The finding from the illustration is complied through a brief discussion in section 6. Finally, section 7; conclude with an emergence of an acceptable approximation techniques for power system design/component of uncertain structure.

2. BLOCK DIAGRAM OF POWER SYSTEM DESIGN

An excitation control of synchronous generator is considered from [Anderson, and Fouad, (1977)] as shown in the Figure 1. It consists of Automatic Voltage Regulator (AVR), Power System Stabilizer (PSS), Exciter, Governor integrated to Turbine and Generator. Briefly this system is explained as; input to the turbine is governed by the governor and output of

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the turbine is fed to the generator which then is passed on to the transmission lines. In this combination, the generator is excited by the exciter that takes input from the generator itself. There are many set connections for exciter to the generator but are beyond our interest. At the governor point also, its governance is performed by the output of the turbine through a proper check between the reference torque ω_r and the incoming input from the turbine ω. Both of this governor and the exciter are externally taken care of by the AVR and the PSS for constant input without any break. A PSS installed in the AVR of the Generator improves the power system stability. It has an excellent cost performance compared to other power system modifications or additions. All of these individual components when taken together result in a very high order system which is not analysable at user end. Considering each of the components will be lengthy and tedious. Thus, only AVR and PSS are taken into consideration for evaluating the techniques of order reduction. Taking uncertainties into account of the parameters, their transfer function provide more realistic design, that result in rewriting the transfer function in uncertain form as stated in section 5.

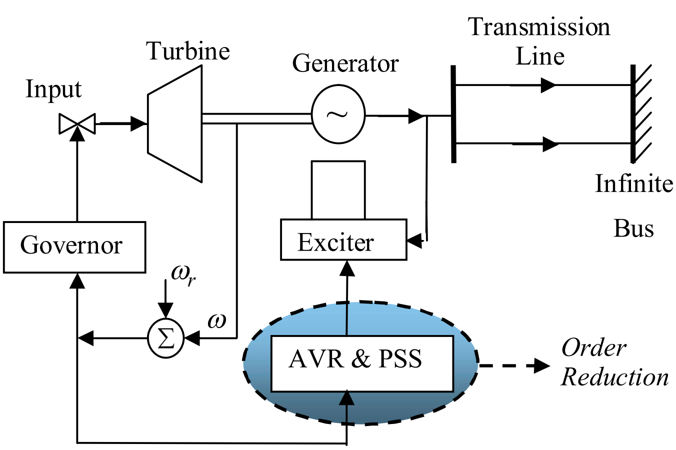

Fig. 1. Block Diagram of Excitation Control of Synchronous Generator

3. BRIEF DISCUSSION ON ALGORITHMS

This section is a discourse of the representation of higher and lower order system followed by the three varied reduction methodologies. Two of the illustrated algorithms are existing namely *DT* and *GD* and one among them designated as *DM* is novel for its outcome. Among the three algorithms; *GD* and *DM* call for an appropriate transformation to their continuous-time equivalent representation. This is mandatory in order to apply continuous-time algorithm on discrete-time domain. To meet this requirement *p*-domain transformation, where $z=1+p$ is performed for being simple and computationally easy. Inverse transformation applicable for these two algorithms to obtain the desired reduced model in *z*-domain is also executed. Tools to validate these algorithms are also discussed in this section.

3.1. Representation

Consider the higher order discrete-time uncertain system transfer function as;

$$G_n(z)=\frac{\left[N_1^-,N_1^+\right]z^{n-1}+\left[N_2^-,N_2^+\right]z^{n-2}+\ldots+\left[N_n^-,N_n^+\right]}{\left[D_0^-,D_0^+\right]z^{n}+\left[D_1^-,D_1^+\right]z^{n-1}+\ldots+\left[D_n^-,D_n^+\right]}=\frac{N_n(z)}{D_n(z)} \quad (1)$$

And its reduced order transfer function with $r<n$ be expressed as

$$H_r(z)=\frac{\left[n_1^-,n_1^+\right]z^{r-1}+\left[n_2^-,n_2^+\right]z^{r-2}+\ldots+\left[n_r^-,n_r^+\right]}{\left[d_0^-,d_0^+\right]z^{r}+\left[d_1^-,d_1^+\right]z^{r-1}+\ldots+\left[d_r^-,d_r^+\right]}=\frac{N_r(z)}{D_r(z)} \quad (2)$$

3.2. Reduction methodologies

3.2.1. Direct Truncation Method [Choudhary and Nagar (2013 a)]

The denominator and numerator polynomial of r^{th} order as stated in equation (2) is

$$D_r(z)=\left[D_r^-,D_r^+\right]z^{r}+\left[D_{r-1}^-,D_{r-1}^+\right]z^{r-1}+\ldots..+\left[D_0^-,D_0^+\right] \quad (3a)$$

$$N_r(z)=\left[N_{r-1}^-,N_{r-1}^+\right]z^{r-1}+\left[N_{r-2}^-,N_{r-2}^+\right]z^{r-2}+\ldots.+\left[N_0^-,N_0^+\right] \quad (3b)$$

3.2.2. Gamma-Delta Approximation [Choudhary and Nagar (2013 b)]

Required *p*-domain transformation result in

$$G_n(p)=\frac{\left[b_1^-,b_1^+\right]p^{n-1}+\left[b_2^-,b_2^+\right]p^{n-2}+\ldots+\left[b_n^-,b_n^+\right]}{\left[a_0^-,a_0^+\right]p^{n}+\left[a_1^-,a_1^+\right]p^{n-1}+\ldots+\left[a_n^-,a_n^+\right]}=\frac{B_n(p)}{A_n(p)} \quad (4)$$

Using the numerator and denominator polynomials from the above transfer function (4), the first two rows of the Routh tables are drafted as shown in Table 1 and 2.

Table 1: Denominator Array for γ Parameters

$\left[a_n^-,a_n^+\right]=\left[a_{0,0}^-,a_{0,0}^+\right]$	$\left[a_{n-2}^-,a_{n-2}^+\right]=\left[a_{0,1}^-,a_{0,1}^+\right]$	$\left[a_{n-4}^-,a_{n-4}^+\right]=\left[a_{0,2}^-,a_{0,2}^+\right]$	…..
$\left[a_{n-1}^-,a_{n-1}^+\right]=\left[a_{1,0}^-,a_{1,0}^+\right]$	$\left[a_{n-3}^-,a_{n-3}^+\right]=\left[a_{1,1}^-,a_{1,1}^+\right]$	$\left[a_{n-5}^-,a_{n-5}^+\right]=\left[a_{1,2}^-,a_{1,2}^+\right]$	…..
….			
$\left[a_{n-1,0}^-,a_{n-1,0}^+\right]=\left[a_{n,0}^-,a_{n,0}^+\right]$			

Entries down the third row of the tables and the $\gamma-\delta$ parameters (both of uncertain structure) are calculated as