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Estimating the dynamic characteristics of natural gas transmission systems

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Extended abstract. The first-principles mathematical models describing natural gas transmission systems are non-linear partial differential equation (PDE) systems with respect to space and time. Those PDE's apply for each individual segment of pipeline, and in addition models describing other components of the transmission systems such as compressors, valves, heat exchangers, storages, etc. are described by ordinary differential equations (ODE) or algebraic equations. All those models can be integrated to one dynamic transmission system model which can be used to investigate the behavior of the system in different operational situations (simulation), or to figure out how the system can be operated in the best way (off-line optimization) or to find the maximum gas transmission capacity in different situations (capacity planning). Commercial transmission system models (TSM's) have been available on the market for many years, and they are known to be very accurate given that the various parameters, such as pipeline geometry, gas composition, friction, compressor characteristics, etc. are correctly entered into the models.

Commercial TSM's are convenient tools when use only for the purpose they have been designed for, but extended use scenarios may provide difficulties. For instance in USA, the natural gas and electrical power markets are getting increasingly integrated [1], [2] and the integration of TSM's and power grid system models tend to be difficult because the execution time of the more complex TSM's becomes prohibitive. Therefore, there is a demand for simplified TSM's. Other motivations for simplified models come from control design and model-predictive control (MPC) for gas transmission systems. In [3] it was demonstrated by a case example that the dynamics of gas transmission systems are, after all, not very non-linear. Simple formulas for the transfer function gains of gas transmission systems were derived in [3] and [4]. There is unfortunately no simple way to conclude the time constants of the linear transfer functions. [4] suggests constrained system identification and [5] a procedure based space discretization and linearization of the PDE's followed by a model reduction step which provides a low-order linear state-space model from which the time constants can be easily extracted.

In [6] a different approach is used: The PDE's are linearized based on certain assumptions and non-rational transfer functions are obtained. Those non-rational transfer functions are then used to provide simulations in the time domain. In [7], the non-rational transfer functions are approximated by Taylor expansions from which the time constants can be easily calculated. The assumptions used do not always hold, and the authors do not present how to treat more complex transmission systems than the single pipeline segments they treat, namely, branched pipelines, pipelines with loops, and transmission systems with multiple pieces of equipment like compressors and valves.

The paper presents a new and practical method to calculate the linear transfer function time constants for gas transmission systems. If a first-principles TSM is available, that is simply used to by multiple simulation experiments - step tests - calculate the time constants so that transmission system parameters (gas throughput, pipeline geometry, friction, compressor data, etc.) are varied according to a pre-defined pattern. The result of these tests is a table of system parameter values and resulting time constants, and simple functions relating parameter values and values of time constants can be derived by regression.

The paper also discusses the very concept of "time constants": it is well known that even the smallest gas transmission system, eg. one short pipeline segment,

has a linearized transfer function with multiple descending de-nominator time constants. It is easy to find the dominating time constant, but how many of the non-dominating are needed to describe the dynamics with reasonable accuracy. In [3] it already became clear that the numerator time constant(s) has relevance depending on the location of the output variable within the transmission system.

References

[1] Carter, R., S. Backhaus, A. Hollis, A. Zlotnik, M. Chertkov, A. Giacomoni and A. Daniels, Impact of Regulatory Change to Coordinate Ga Pipelines and Power Systems, Pipeline Simulation Interest Group (PSIG) annual meeting, May 2016, Vancouver, Canada

[2] Zlotnik, A., M. Chertkov, R. Carter, A. Hollis, A. Daniels and S. Backhaus, Using Power Grid Schedules in Dynamic Optimization of Gas Pipelines, Pipeline Simulation Interest Group (PSIG) annual meeting, May 2016, Vancouver, Canada

[3] Aalto, H. , Optimal Control of Gas Pipeline Networks, a real-time, model-based, receding horizon optimisation approach, 186 pages, VDM Verlag Dr. Müller Aktien-gesellschaft & Co. KG, Saarbrücken, Germany, ISBN 978-3-639-09111-3, 2008

[4] Aalto, H., Model Predictive Control of Natural Gas Pipeline Systems - a case for Constrained System Identification 9th IFAC symposium on Control of Power and Energy Systems, 9-11 December 2015, New Delhi, India, www.ifac-papersonline.net

[5] Aalto, H., Transfer functions for Natural Gas Pipeline Systems, 17th IFAC World Congress, July 6-11 2008, Seoul, South Korea, www.ifac-papersonline.net

[6] P. Lopes dos Santos, T-P Azevedo Perdicou'lis, J. A. Ramos, G. Jank, J. L. Martins de Carvalho and J. Milhinhos, A Lumped Transfer Function Model for High Pressure Gas Pipelines, 49th IEEE Conference on Decision and Control (CDC), 15-17 Dec. 2010, Atlanta, USA

[7] Wen, K., Z. Xia, W. Yu and J. Gong, A New Lumped Parameter Model for Natural Gas Pipelines in State Space, Energies 2018, 11, 1971, www.mdpi.com/journal/energies