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HYBRID SYSTEMS MODELING FOR GAS TRANSMISSION NETWORK

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Abstract: Expansion of gas transmission networks and advancement in related automation systems has made these networks more complex. Study of these networks in an analytical approch, can help us in their design, management and optimization. We use a hybrid model based on hybrid automata to model the network. By using abstraction methods, a finite state automaton can be achieved which is used for intelligent control of the network. Due to lack of a decision model, Q-learning method is selected for decision-making purpose in which the proposed hybrid model makes our environment.

Keywords: *Hybrid systems*, *Discrete Event Systems*, *Intelligent Control, Machine Learning*

1. INTRODUCTION

Large-scale systems such as Power Transmission Networks, Oil and Gas Transmission Networks and Transportation systems have critical rule in all downstream industries. These systems grow rapidly and their management and analysis need more attentions, especially, in a systematic way. Today, those efficient Analysis and control is the matter of new researches (Chapman, et al., 2002).

In the Oil and Gas, we have different prominent features that make problem more complex. Large delays in response to either smooth or rapid change of variables and dependency to time and space make analysis difficult. Optimal operation of these networks widely considered in literatures (Alato, 2005; Osiadacz, et al.,1994; Carter, 1998; Kelling, 2000), that reduces losses and saves money. The main assumption of these works is that the system widely maintains its liveness and safe operation, which needs more considerations.

However, Such Systems belong to hybrid systems and a general class of hybrid systems can be represented using *hybrid automaton*. Hybrid automaton are an extension of state automaton, which includes continuous and discrete dynamics.

For complexity reason, *abstraction* methods usually utilize to reduce the underlying problem to a simpler one. These approaches make a system more abstract in a way that it preserves properties being analyzed while hiding details that are of no interest. In abstraction, either the continuous dynamics must be restricted, for example in timed and rectangular hybrid systems or the discrete dynamics must be restricted, as is the case for o-minimal hybrid systems (Koutsoukos, et al., 2000). Thus, in large-scale and hybrid systems, we often investigate a simpler model, which is derived from original system.

In first method, we approximate the continuous behavior of system by a finite discrete behavior. So, we yield a unified model in discrete form. However, this approximation requires being *safe*, meaning that a controller must be guaranteed to provide same logical specifications for both the underlying concrete system and the abstract model. Besides the safety problem, we are interest in solving this problem in an optimal way. Moreover, this matter highlights the need of flexible techniques for approximation, which can provide different grades of approximation. By such approximator, that preserves many important behaviors of system in abstraction procedure, makes it possible doing analysis in a simpler level of complexity and extend results to the concrete system.

However, in our design the abstracted model of the underlying hybrid system is a Discrete Event Systems (DES) and needs using DES approaches and its extensions. In the late 1980s, Ramadge and Wonham (Ramadge, et al., 1989) proposed the Supervisory Control Theory (SCT), which applies feedback theory to DESs that is modeled by automata. The supervisory control theory is a method for automatically synthesizing supervisors that restrict the behavior of a plant such that the given specifications are fulfilled as much as possible (for further reading, see (Ramadge, et al., 1989)). Today, this approach is common in discrete event system modeling and analysis and many researches are employing this framework. But, RW framework is based on automata and language theory (and symbolic computation), which is far from linear system theory principles.

Moreover, for analysis of these types of problems, which often meet in lower level analysis of hybrid systems many approaches have been proposed (Cohen, et al., 1989; Murata, 1989; Harel, 1987; Ho, 1989). In linear system theory, we have many powerful tools for analysis of dynamical system, which can reuse in discrete event systems but most of mentioned approach does not have strong connection to classical system theory.

In 1981, the researchers in INRIA started working on what we now know as Max-algebra; a system theoretic approach for discrete event systems. Although, this approach is well suited in some applications (Doustmohammadi, 1993; Kamen, 1993) but after twenty-six years, it is not as general as linear system theory. Recently, fuzzy discrete event systems (FDES) are introduced which convert symbolic computation of DES to a mathematical framework.

In this paper, we present a hybrid model of gas transmission network. This network can model using hybrid automaton. Hybrid automaton is a suitable tool for modeling large-scale systems. Moreover, in contrast with petri-nets and its extensions, this framework brings decidability property, which in complex systems is an important subject. A problem is said to be decidable if there exists an algorithm to solve that problem and otherwise, is said to be undecidable.

However, utilization of this feature needs (or perhaps, are easier) converting the underlying hybrid system to a unified discrete event model. Then, we can decide about important properties of this discrete event system and extend these results to the concrete one.

Today, the analysis of complex automation systems becomes more important. However, dependencies between infrastructures such as power transmission network, oil and gas transmission network and telecommunication network make this issue prominent. In reality, we have some events that are not observable to operator, because of the lack of sensors or detection means, too high cost of detection, or difficulty in information transmission. Thus, some behavior of the underlying system is not observable to user.

In this paper, we first model some important components of gas transmission network using hybrid automaton. This model for a part of Iranian Gas Transmission Network is also implemented in Simulink™ and Stateflow™ . Then, we present an abstraction method named *Fuzzy abstraction* which yields a variable structure automaton. Based on this model, we proposed a reinforcement learning method for tuning variable transition of a supervisory controller. However, the membership degree of this variables are as our control variables. In a decision support system, which can be used in supervisory control systems, these transitions yield using if-then rules (and some other fusion rules).

The major advantage of our model is its interactivity and reconfigurability, which makes it a suitable framework for diagnosing and management purpose. Also, based on this model, analysis and systematic design of control system is possible.

The rest of the paper is organized as follows. In section 2, we present a brief introduction to Natural Gas Transmission Network, followed by section 3 that models this network based on hybrid automaton. In section 4, This network is then implemented in SIMULINK™/Stateflow™ which, provides a suitable test bed for further researches. Section 5 is devoted to present control system design. Section 6 concludes the paper.

2. NATURAL GAS TRANSMISSION NETWORK

Natural gas pipeline networks, or *pipeline systems*, are used to transport gas from sources to consumers over long distances. The distance from a source to a consumer may be thousands of kilometers. The gas in the pipeline is pressurized in order to maintain a pressure difference necessary for moving the gas. *Compressors* are used to pressurize the gas. These are needed at regular intervals along the pipeline-usually every 50 to 150 kilometers, since the gas pressure decreases rapidly due to frictional losses. The most elementary components of a pipeline system are pipeline segments and compressors. Other components of pipeline system are valves (discrete or continuously operating) and gas storages. Long-distance transmission pipelines operate under high pressures and gas users at the off-takes use *pressure reduction stations* to adapt the gas pressure to their needs (Alato, 2005).

However, in this paper we only investigate the following components: Pipeline Segments, Compressors (compressor Stations), Line Break Valves and other type of valves. Modeling of these components is done based on hybrid automaton. A major advantage of this modeling approach is its user friendliness that can be easily used and generalized for other relevant applications. In pipeline systems, compressor stations are the most complex parts of the model. Fig.1, illustrates connections between components in a compressor station.

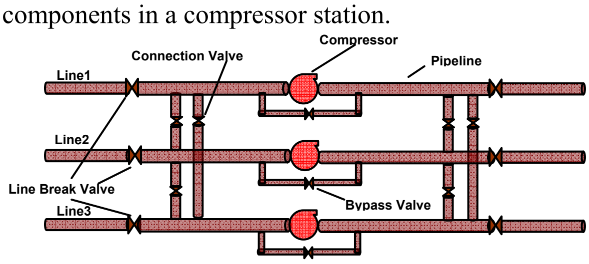

Fig.1 Components of a compressor station

In the following, we discuss modeling of network components.