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Optimization of a compressed natural gas station operation to minimize energy cost

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Abstract

Compressed natural gas (CNG) is one of the growing alternatives to liquid petroleum fuels for propulsion of motor vehicles. Lower greenhouse gas emissions as well as increased durability of vehicle engines are the main properties of CNG that make it a better alternative to petrol and diesel. CNG refueling infrastructure is vital to the expansion of consumer adoption of CNG vehicles. The economical operation of CNG fueling stations is beneficial to the station operators and consumers, by reducing cost of fuel delivery. The present study is concerned with the optimal scheduling of compressor operation in a CNG fueling station to achieve reduced cost of energy in a time-of-use electricity tariff environment. The cascade fast fill station is modelled as a single storage mass flow system with storage refilling optimally controlled to achieve minimum cost of electricity in supplying a typical day gas demand profile. The open loop optimization strategy shows the potential to achieve savings of 59.28% in cost of electricity for operating the compressor, while also minimizing compressor wear and tear.

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Keywords: Compressed natural gas; optimal control; time-of-use

1. Introduction

The need to address the global challenges of climate change, air pollution and energy dependence brought about by the use of different liquid petroleum fuels has resulted in an increase in the adoption of Compressed Natural Gas (CNG) for motor vehicle propulsion [1]. CNG has the lowest greenhouse gas emissions among hydrocarbon fuels, making it a suitable option for cleaner combustion energy which also results in a lower total cost of ownership (TCO) of CNG powered vehicles when compared with petrol or diesel alternatives [2]. The expansion in the number of CNG powered motor vehicles has corresponded with an expansion in CNG refueling infrastructure, some of which has been implemented domestically by vehicle owners and commercially at roadside refueling stations [3]. CNG fueling points are operated using

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either the time-fill or fast-fill strategy with the time-fill strategy being adopted for applications that can allow for longer filling times while the fast-fill strategy is used in fueling stations with vehicle filling times of less than 5 minutes, comparable to filling times at petrol or diesel filling stations [4]. Electricity powered gas compressors used at CNG refueling points are a significant electrical load and efficient operation strategies are necessary to achieve minimum operation costs [5].

In literature, the fast-fill station has been modelled by different researchers starting with [6] who modelled the fast-fill process based on the first law of thermodynamics between the vehicle reservoir and a single reservoir storage. [6] has been expanded by other researchers who modelled the fast-fill process with consideration for gas flow with respect to different system components and operating conditions [7–9]. Research on the interaction between CNG refueling infrastructure and the electricity distribution networks is still scarce and more investigations should be done in this area [5].

The present study seeks to minimize the operation cost of a fast-fill CNG fueling station by reducing energy cost through the use of an open loop optimization of the switching of the compressor in a time-of-use (TOU) electricity tariff environment. To the best of the authors' knowledge this introductory study is the first attempt to implement a controller to achieve electric load shifting for CNG fueling stations taking advantage of TOU electricity pricing programs implemented by utility companies for demand response.

2. Problem Formulation

Figure 1 shows the schematic diagram of a fast-fill refueling station. The compressor on/off status is set through switch u. When the compressor is turned on, compressed gas flows into the cascade storage through

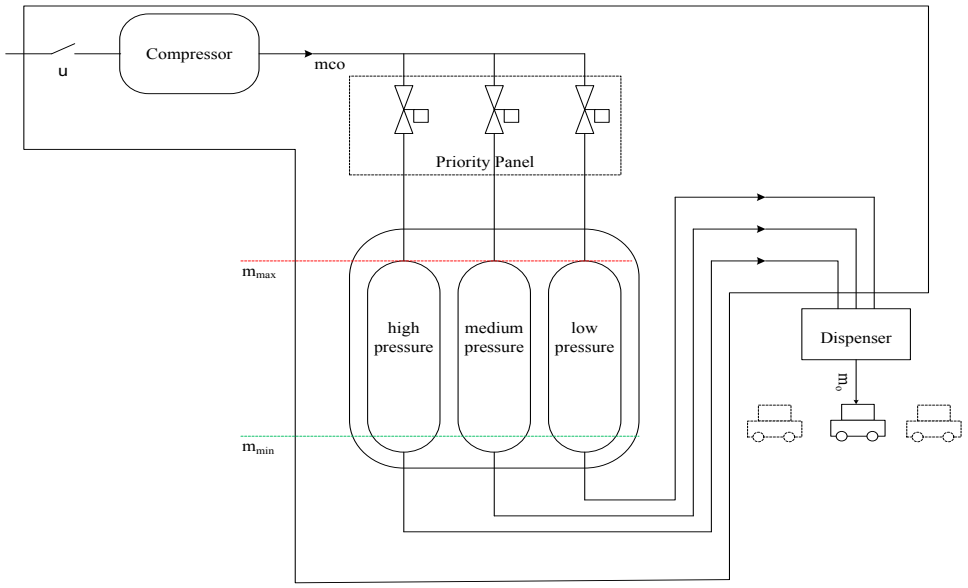

Figure 1: Schematic diagram of a fast-fill CNG refuelling station

the priority panel at a mass flow rate m_{co}. The priority panel runs on an algorithm that determines the reservoir connected to the compressor between the low pressure, medium pressure and high pressure reservoirs [9]. The storage in the present study is modelled as a single mass storage system with a maximum storage mass m_{max} and a minimum mass m_{min}. Gas in the storage is transferred to the vehicle tank through the dispenser whose algorithm determines the reservoir to which the vehicle tank is connected depending