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Determination of Water Distribution Network Resistance Coefficient and Hydraulic Capacity

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Abstract

This paper describes the development of the surplus power factor *s* that characterizes the reliability of the hydraulic system and the values of which vary between 0 to 1. In order to calculate the *s* factor for water distribution networks (WDNs), a network resistance coefficient *C* has to be determined. This paper compares different approaches in order to calculate the coefficient *C* and determine the *s* factor for WDNs.

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1. Introduction

An extensive rehabilitation program for Tallinn city (Estonia) WDNs started in 1996. Data about the water distribution system (WDS) characteristics (pipes, demands, water quality, etc.) were scattered then and no hydraulic models for the system were available. Therefore data collection took several years, and initial hydraulic models were developed. In addition, several years were spent on adequate measurement data collection about actual pressures and flows in the system. In 2003 the hydraulic models were calibrated to create a basis for a further rehabilitation program.

Early rehabilitation decisions were mainly based on water quality issues [1]. Since the relict from the Soviet era was an over-dimensioned system, the main concern was slow velocities in the WDN that caused long water age before consumption and deteriorated water quality. Therefore, targets in the plan of action were to reduce the diameters where

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pipes needed replacement due to bad installation quality. When the hydraulic models provided a good basis for analysis in terms of water quality and overall performance in the WDN, it was realised that to evaluate the WDN piping it was essential to study hydraulic power transmission. Based on the studies conducted by Park et al. [2], the theory of hydraulic power transmission was developed further. The idea was to find optimum solutions for the hydraulic power transmission in the system and at the same time to analyse the reliability of the WDSs. Therefore, the surplus power factor [3] was introduced.

The basis for the surplus power factor calculation is the correct determination of the WDN resistance coefficient *C*. A method for the determination of the *C* value in WDNs is presented in [4]. This paper describes different approaches applicable to the determination of the surplus power factor and the network resistance coefficient *C* values.

2. Development of Surplus Power Factor Analysis

A simple case of hydraulic power in an individual pipe was examined by Vaabel et al. [3]. The hydraulic power at the outlet of the pipe is defined as

$$P_u = \gamma\left(Q_0 H_0 - cQ_0^{a+1}\right) \tag{1}$$

where P_u is the useful power at the outlet of the pipe, γ is the specific weight of water, H_0 is the head at the inlet of the pipe, Q_0 is the flow entering the pipe, c is the the resistance coefficient of the pipe, and a is the flow exponent. For a single pipe, the coefficient of the critical outlet power k is defined as the ratio between the maximum hydraulic power and the useful power at the outlet of the pipe

$$k = \frac{P_u}{P_{u\max}} \tag{2}$$

For the latter, the surplus power factor s is defined as

$$s = 1 - k \tag{3}$$

or

$$s = 1 - \frac{a+1}{a}\left[1 - \frac{1}{a+1}\frac{Q_0^a}{Q_{0\max}^a}\right]\frac{Q_0}{Q_{0\max}} \tag{4}$$

Eq. (4) was the basis for the rehabilitation strategy for Tallinn WDNs. Initially, optimum solutions were analysed in each WDN pipe section and the results were averaged to the whole network. Thus, although the theory could be adequately applied to each pipe section between the numerous nodes in the WDN, the results for the whole WDN were not as expected. The reason is that since the optimum power loss for the most effective power transmission is one third of the initial head and if this approach is applied to all the pipes in the WDN, the customers would end up with no water (i.e., too high power loss in the system).

Next, the focus shifted to the power loss between the source and the target node. The network resistance coefficient *C* was determined with the power loss *h* between the heads at the source node (pumping station) and the target node as