Renewable and Sustainable Energy Reviews 49 (2015) 1100–1113

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Sediment erosion in hydro turbines and its effect on the flow around guide vanes of Francis turbine

Biraj Singh Thapa [a,*], Ole Gunnar Dahlhaug [a], Bhola Thapa [b]

[a] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway
[b] Department of Mechanical Engineering, Kathmandu University, Dhulikhel, Nepal

A R T I C L E I N F O

Article history:
Received 10 September 2014
Received in revised form
27 April 2015
Accepted 30 April 2015
Available online 21 May 2015

Keywords:
Sediment erosion
Francis turbine
Guide vane
Secondary flow
Efficiency

A B S T R A C T

Erosion of material surface due to collision of solid particles has been a challenge to several fields of engineering. Despite of centuries of investigations and research, the exact phenomenon of erosion of surface by the solid particles has not been fully understood. Increasing number of hydropower plants are being built in the regions where rivers are heavily loaded with sediments. This induces material erosion in hydro turbines, leading to change in flow pattern, losses in efficiency, vibrations and even final breakdown of turbine components. To overcome sediment erosion related failures, development of erosion resistant alloys, coatings of the components, and optimization of hydraulic design of the components, are the important practices. In Francis turbines, erosion causes increase of clearance gap between guide vanes and facing plates and cross flow occurs from this increased gap. This cross flow together with other secondary flows disturbs the velocity profile at the runner inlet. Change in velocity profile at the inlet causes additional erosion damage and other undesired effects in the turbine runner. Most of the past studies in Francis turbine were focused to understand the flow phenomenon inside the turbine components and to analyze their effects on design improvements. There is still a need of further fundamental research to understand the effects of sediment erosion of turbine components on the flow phenomenon, and developing better designs of hydro turbines to minimize those effects.

Contents

1. Introduction

Global primary energy consumption will increase about 1.5 fold, from 11,743 Mtoe in 2010 to 17,517 Mtoe in 2035 [1]. Fossil fuels account for about 90% of primary energy consumption at present. Due to its unsustainability, and environmental and health effects, alternative and clean resources of energy have to be tapped further more in future. With about 15% of global electricity supply, hydropower serves as the major contributor of renewable and sustainable source. The theoretical reserve of hydro energy is 39,097 TW h/yr, with a technical availability about 14,653 TW h/yr and an economic availability about 8728 TW h/yr [2]. By 2007 the installed capacity of economically available hydro power resources worldwide has crossed 35%, with Europe and North America having highest degree of development equaling 71% and 65% respectively. Fig. 1 shows the distribution of total hydropower potential across the different region of world. Most of the untapped hydro energy resources lie in South Asian and South American countries, where demand of energy is the highest and will keep growing for some decades as huge population is in the transition phase of poverty and development [3]. However,

* Corresponding author. Tel.: +47 47167671.
E-mail address: biraj.s.thapa@ntnu.no (B.S. Thapa).

http://dx.doi.org/10.1016/j.rser.2015.04.178
1364-0321/

both of these regions suffer from soil erosion due to weak geological formation and heavy precipitation in short time interval causing floods. In the central Himalaya and Ganges Plain more than 80% of annual rainfall occurs during the Indian summer monsoon season (May–October) [4]. This causes drastic increase of sediment concentration in rivers every year.

Run off the river hydro power projects across these region suffers several operational and maintained challenges, which are often associated with financial losses. The concentration of sediments in the rivers during extreme conditions can reach up 57,000 ppm and the amount of hard minerals in sediments is as high as 80% [8]. Loss of turbine efficiency in a power plant in Nepal, due to sediment erosion damage, has been measured to be 4% and 8% respectively in full load and part load conditions, within the short operational period of 01 September–11 November, 2003 [8]. Sediment monitoring in the same period have indicated that approximately 6900 t of sediment had passed through this unit during the test period.

Similar cases of sediment erosion of turbine components and associated losses have been reported from power plants from India [9], Bhutan [10] and also from South American continents [7]. Fig. 2 shows typical damages of hydro turbine components from different power plants operating under heavy sediment load. Comparable patterns of turbine erosion, operational challenges and performance losses have been observed from different power plants, operating in sediment environment, across the continents.

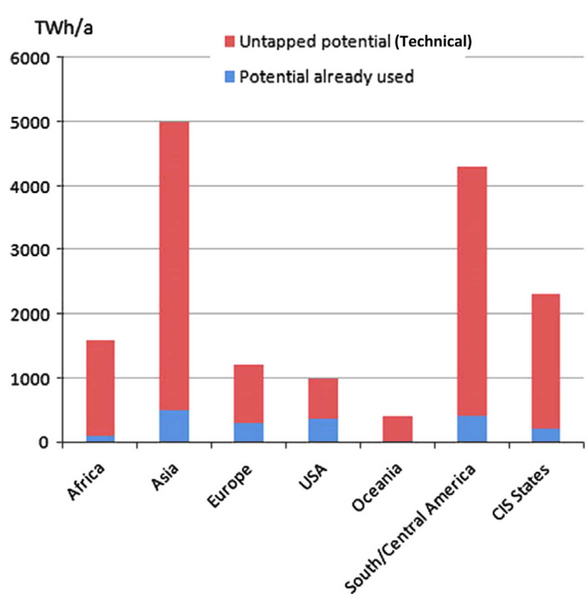


Fig. 1. Hydropower potential, untapped and already uses power. Adapted from [3].

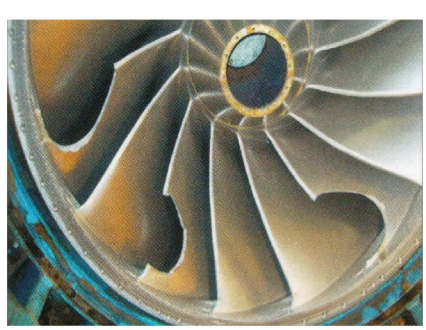
Several methods have been developed and implemented to stop or reduce sediments reaching and damaging the turbine components. Important and conventional ones include, prevention of sedimentation in the catchment areas [11], tapping sediments at intakes [12], applying preventative coatings on the turbine components exposed to high velocity water [13] and also shutting down the power plant in excessive sediment loads intakes [14]. Despite of these efforts erosion damage of turbine components has remained as a major challenge of hydropower development under the Himalayan and Andes basins. This has generated much interest among the researchers to find the alternative and sustainable solution to this age old problem. A new method of manufacturing Francis turbine has been developed to allow protective coatings to be applied on all the surfaces of runner and guide vanes [15]. The components of turbine runner are fabricated separately and are bolted together after high velocity oxy-fuel (HVOF) coating has been applied very precisely. This technique has shown better performance compared to the conventional methods in 42 MW Chawa hydropower plant in Peru.

Recent studies have shown that the geometric profile of runner blade of Francis turbines can be optimized to reduce relative velocity of water and hence sediment erosion of the blades itself [16]. Analytical tool has been developed and several design options were investigated. It has been proposed that with the new design methods, sediment erosion in Francis runner blades can be reduced by 30%. However, from numerical studies it was also found such design concepts will accelerate erosion in guide vanes due to change in flow around guide vanes [17]. Hence there is still need of further investigation for reducing sediment erosion damage in Francis turbine components by design optimization.

2. Erosion wear in engineering materials and hydro turbines

References to scientific studies on abrasion of hard minerals by to sand particles can be found from 1873 [18]. A comprehensive work on erosion of surfaces by solid particle has been published by Finnie on 1960 [19]. This work includes literature review of past research followed by theoretical and analytical analysis of the erosion with experimental validations. He categorized his studies to two main types of material behavior, ductile and brittle. It was observed that the ductile materials will undergo weight loss by the process of plastic deformation in which material is removed by the displacing or cutting action of the eroding particle. In a brittle material, on the other hand, material will be removed by the intersection of cracks, which is caused by the impact of the eroding particle. Based on this theory and also from earlier studies it was concluded that in general ductile material will have maximum erosion at the jet angle close to 30° and that for brittle

48 MW*3 Francis turbine at Kaligandaki Power plant, Nepal [5]



250 MW*6 Francis turbine at Nathpa Jhakri Power plant, India [6]

23 MW*2 Francis turbine at Chawa Power plant, Peru [7]

Fig. 2. Sediment erosion in Francis turbine runners from various Power plant.