Annals of Nuclear Energy 112 (2018) 177–188

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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

Review

A survey of the state of condition-based maintenance (CBM) in the nuclear power industry

R.M. Ayo-Imoru *, A.C. Cilliers

North West University, School for Mechanical and Nuclear Engineering, Hoffman street, Potchefstroom, North West Province 2530, South Africa

ARTICLE INFO

Article history:
Received 11 February 2017
Received in revised form 2 October 2017
Accepted 5 October 2017

Keywords:
Condition-based maintenance
Monitoring
Diagnostics
Prognostic
Maintenance stakeholders

ABSTRACT

Condition-based maintenance (CBM) involves undertaking maintenance activities based on the health of the system. CBM has found useful applications in many industries. This paper presents a survey on the state of condition-based maintenance in the nuclear industry. This is achieved by systematically looking at the major phases of CBM, which are monitoring, diagnostics and prognostics. A methodical review has been done on these aspects of CBM. This includes the current practices in the nuclear industry and the ongoing research on the different methods and technologies being developed. This will give maintenance stakeholders and researchers an overview of the current practices and extent of research undertaken on condition-based maintenance in the nuclear industry.

Contents

* Corresponding author.
E-mail address: ronilekins@gmail.com (R.M. Ayo-Imoru).

https://doi.org/10.1016/j.anucene.2017.10.010
0306-4549/

1. Introduction

Maintenance has evolved over time as advancement in technology and fast-growing research has been put into building more efficient and reliable systems. In the early days of production, the approach to maintenance was that of "fix it after it fails" method. This was because simple machines were employed in production and demand was not so high. Therefore, the industries could afford to have downtimes; this type of maintenance is termed corrective maintenance. The periods after the world war II, the world began to experience great advancement in technology and the industries had more complex machines, the demands got higher and down times could mean being out of business. As a result, maintenance approach has evolved from the corrective approach to a new approach, which is the preventive maintenance. The preventive type of maintenance from the 1970's, which is the periodic maintenance, involved scheduling maintenance at regular intervals to avoid failure. Over time as technology kept advancing, interest has shifted from "avoiding failure" type of maintenance to a more cost-effective maintenance. This has brought about another type of preventive maintenance, which is the condition-based maintenance (CBM). CBM involves undertaking maintenance activities based on the health/ condition/level of degradation of the system/ equipment. In Table 1, the summary of how maintenance has evolved over time and the characteristics of the different types of maintenance is portrayed (Moubray, 1995; Agency, 2007).

CBM has found wide applications in many industries like aerospace, electronics, chemical industry, military and many critical facilities with good results. This paper intends to explore the state of CBM in the nuclear industry.

This paper is organized in seven (9) sections. The first section is the introduction. The second section explores CBM in the nuclear industry. The third section explains the state of monitoring. The fourth section describes detection in the nuclear industry, while the fifth section discusses diagnostics in the nuclear industry. The sixth section explicates the state of prognostics in the nuclear industry. The seventh and eight section discusses the different modelling methods used in CBM, and also strength, weakness, opportunity and threat (SWOT) analysis of these modelling methods. The last section is the conclusion.

2. Condition-based maintenance (CBM) in the nuclear industry

The nuclear industry is a major contributor to the world electricity. The nuclear industry does not just produce electricity, but it provides clean energy, which is free of greenhouse gases. Electricity from the nuclear plant is used mostly for base-load because it is reliable and steady. The nuclear power contribution to world electricity as at 1999 was 17% (Davies et al., 2000). Davies et.al mentioned that this percentage will most likely reduce in the coming decades due to challenges faced in the nuclear industry. This projection is a reality today because data from 1999 to 2015 has shown a decreasing trend of nuclear contribution to the world electricity. This is depicted in the Fig. 1 below. In the the last decade the contribution from nuclear power has been decreasing as given by world energy outlook (IEA, 2017).

One major factor affecting the nuclear power plant (NPP) is producing electricity in a cost-effective manner without jeopardizing safety (which is of highest priority in the nuclear industry). In NPPs, the cost of operations and maintenance (O&M) is about 60–70% of the total cost of generation (Coble et al., 2012). Therefore, to reduce the cost of producing electricity, one important aspect to look at is the maintenance. For the NPP to compete successfully with other energy sources, the nuclear industry must reduce the cost of generating electricity, which can be made possible through a condition-based maintenance strategy.

CBM has been widely used in other critical facilities like the aerospace, naval ships with very good outcomes. In addition, in the nuclear industry, places like the USA and Europe have incorporated CBM to their maintenance strategy and this has resulted in reduced maintenance cost and increased output. Bond et al. in their analyses suggested that applying CBM to all key equipment in legacy power plants in the United States will result in fleet-wide savings of over $1 billion per year (Bond et al., 2011). With CBM, the NPP will optimize its performance, as maintenance will be done only when the plant condition requires it. Many of the NPPs across the world are ageing and are pressing for life extension which makes ageing management one of the key issues in the nuclear industry (Pelo, 2013). At present, CBM is playing a key role in the NPP life extension programmes in the United States.

NPP equipment is majorly categorized into three (3), which are, structures, systems and components (SSC). These SSCs are further

Table 1
Types of Maintenance system and their characteristics.

Maintenance system					
Maintenance type		Period	Basis	Approach	Outcomes
Corrective		1950s	Failure	Fix it after it fails	❖ Downtimes ❖ Unplanned outages ❖ High cost of operation ❖ High cost of production ❖ High cost of repairs ❖ Lots of emergencies ❖ Unsatisfied customer ❖ Stressed management
Preventive	Time based	1970s	Regular intervals	Service/ repair at intervals	❖ Reduced downtimes ❖ Planned maintenance ❖ Costly maintenance ❖ Lower cost of operation ❖ Replacement of good parts ❖ Less emergencies ❖ Unnecessary maintenance ❖ Satisfied customer ❖ Unsatisfied management
	Condition based	Current practice	Plant condition	Service/repair based on level of degradation	❖ Reduced downtimes ❖ Planned maintenance ❖ Cost effective maintenance ❖ Lower cost of operation ❖ Replacement of only bad component parts ❖ Increased production ❖ Plant life extension ❖ Less emergency activities ❖ Satisfied customer ❖ Satisfied management