SYSTEM IDENTIFICATION AND ADAPTIVE SELF-TUNING CONTROL FOR IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM

EZZ ELDIN BALLA MOHAMED HUSSEIN

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Dedicated to the entire BALLA's
And to all those that believed in me

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ABSTRACT

Pipeline infrastructure has become a very popular tool for transferring and distributing oil, gas and raw materials. Many of these pipelines extend along hundreds of miles and pass through remote, harsh and corrosive areas. This raises the prospect of cracks in their walls and cause leaks. In case of pipelines fail due to corrosion resulting in leakage, they will often lead to loss of products followed by environmental and financial damages on a national scale. Therefore, protecting materials and structures against corrosion is a significant issue especially in tropical countries such as Malaysia which has high humidity climate (corrosiveness factor). This latest, promotes the need for specialized research to be done for preventing corrosion. Consequently, in this study we have focused on the most practical method of cathodic protection systems which is impressed current cathodic protection (ICCP) system. This system is widely used to prevent the external corrosion of carbon steel structures; especially those are used in underground pipelines. Basically, in this project the theoretical background and the concepts of ICCP systems have been discussed. An effective laboratory scale for ICCP systems was built according to specific concepts has been clarified. Then, parametric model of ICCP systems was obtained using system identification approach. Furthermore, to enhance the performance of ICCP systems, proportional-integral (PI) and direct self-tuning generalized minimum variance (ST GMV) controllers have been designed. Additionally, simulation and experimental works have been carried out to control ICCP systems at different operating conditions. Finally, the ST GMV controller leads to improve the system speed response and to decrease the integral of absolute error, which is lower value compared to close loop using PI controller.

ABSTRAK

Infrastruktur paip telah menjadi peralatan yang penting untuk memindah dan mengedarkan minyak, gas dan bahan-bahan mentah. Kebanyakkan paip-paip ini dipasang diunjurkan jauh sehingga beratus-ratus kilometer. Ada diantara paip-paip ini melalui kawasan-kawasan pedalaman, termasuk juga kawasan yang berdepan dengan hakisan. Ini meningkatkan kemungkinan berlaku retakan dan seterusnya kebocoran. Sekiranya kegagalan sistem perpaipan ini adalah disebabkan oleh hakisan yang disebabkan oleh kebocoran, ini selanjutnya akan mengakibatkan kerugian produk, dan kerosakan alam sekitar juga termasuk peningkatan dalam kerugian kos pada skala peringkat kebangsaan. Oleh yang demikian, bagi negara tropika seperti Malaysia yang mana iklimnya panas dan lembap, keperluan untuk melindungi material dan struktur daripada hakisan adalah amat penting. Dalam kajian ini, fokus kami adalah menggunakan kaedah yang paling praktikal dalam sistem perlindungan katod, iaitu sistem perlindungan katod arus teruja (ICCP). Sistem ini digunakan secara meluas untuk mengelakkan hakisan luaran oleh struktur keluli karbon; terutamanya untuk perpaipan didalam tanah. Pada asasnya, didalam projek ini, latar belakang teori dan konsep sistem ICCP telah dibincnagkan.satu makmal efektif untuk sistem ICCP telah dibina berdasarkan konsep tertentu telah dijelaskan. Kemudian, model parametrik sistem ICCP telah diperolehi dengan menggunakan sistem pengenalan identiti. Tambahan pula, untuk meningkatkan prestasi sistem ICCP, pengawal penalaan perkadaran dan penalaan kamiran (PI) juga penalaan diri langsung dengan varians minimum umu (ST GMV) telah direka. Akhirnya, ST GMV pengawal mampu memperbaiki kelajuan tindak balas sistem dan mengurangkan kamiran kesilapan mutlak, yang merupakan nilai yang lebih rendah berbanding menggunakan pengawal PI gelung tutup.

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LIST OF ABBREVIATIONS

CP	- Cathodic Protection
ICCP	- Impressed Current Cathodic Protection
PHMSA	- Pipeline and Hazardous Materials Safety Administration
TR	- Transformer Rectifier
NACE	- National Association of Corrosion Engineers
DC	- Direct Current
AC	- Alternating Current
PI	- Proportional–Integral
PID	- Proportional–Integral-Derivative
FLC	- Fuzzy Logic Controller
NN	- Neural Networks
ST	- Self-Tuning
STC	- Self-Tuning Control
MV	- Minimum Variance
MVC	- Minimum Variance Control
GMV	- Generalized Minimum Variance
RLS	- Recursive Least Square
RE	- Reference Electrode
CCSRE	- Copper/Copper Sulfate Reference Electrode
DAQ	- Data Acquisition Card
PC	- Personal Computer
SISO	- Single Input Single Output
PVC	- Polyvinyl Chloride
PRBS	- Pseudo Random Binary Sequence
GUI	- Graphical User Interface
ARX	- Auto-Regressive with Exogenous Input

ARMAX	- Auto-Regressive Moving Average with Exogenous Input
OE	- Output-Error
BJ	- Box-Jenkins
RTCS	- Real-Time Control System
PEM	- Prediction-Error Method
FPE	- Final Prediction Error
TF	- Transfer Functions
IAE	- Integral of Absolute Error

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter discusses about the introduction of the study which is consist of; background of study, significance of study, problem statement, project objectives, and the project scope.

1.2 Background of Study

The Materials Corrosion phenomenon has become a global significant problem. Corrosion weakens strength and cause failure on material. The general definition of corrosion is dissolution or destruction of a material as a result of electrochemical reactions with its environment. Most of the materials which undergo corrosion are metals; hence most of the corrosion definitions have been specified to metals [1, 2]. However, Mars G. Fontana suggested that all materials including ceramic, polymer and other non-metallic materials which are contributed into the corrosion should be taken care as well [3].

Protecting materials against corrosion is a significant issue especially in tropical countries such as Malaysia which has high humidity climate (corrosiveness factor). The annual cost of corrosion in many countries is very high, for example, “In the United States the annual corrosion cost is USD$ 40 billion or RM 140 billion” [4]. Therefore, preventing corrosion need to be done onto materials in order to reduce corrosion rate, so that less materials and money being wasted.

However, the previous mentioned definition of corrosion encompasses all materials, in this project we have concentrated on metal-corrosion which is linked to the carbon steel that is used in underground pipelines. In the fact that, soil corrosiveness varies over a wide range as a result of a variety of the compositions and solutions. Moreover, there are many factors affect the corrosiveness of the soil such as resistivity, humidity, chlorides, sulfates, temperature and pH [2].

Several approaches have been used to protect materials against corrosion, for an instant, coating system, cathodic and anodic protection systems. However, cathodic protection has a great history back to around two centuries. Sir Humphry Davy reported in 1824 that “copper could be successfully protected against corrosion by coupling it to iron or zinc. He recommended cathodic protection of copper-sheathed ships, employing sacrificial blocks of iron attached to the hull in the ratio of iron to copper surface about 1:100” [5].

In general, cathodic protection (CP) is a technique has been used for a long time to prevent metal corrosion by making it a cathode of an electrochemical cell. This technique is universally used in protecting the external surface of pipelines, underground storage tanks, ship hulls and sub-sea structures, etc. CP was used mainly to prevent further corrosion after repair of damaged structures. However, recently cathodic protection has been incorporated in new constructions in an effort to prevent corrosion from being started by applying one of its two methods; galvanic anode or impressed current cathodic protection [6, 7].

In this study, we have focused on the most practical method of cathodic protection which is known by impressed current cathodic protection (ICCP) system. This system is widely used to prevent the external corrosion of carbon steel structures; especially those are used in underground oil and gas pipelines. The corrosion protection will be achieved by using ICCP methods, if the impressed current is adequate to shift the potential of a metal to a level or protection range at which corrosion is not occurring or negligible.

1.3 Significance of Study

Billions of dollars of crude oil or natural gas are transferred through a widespread network of pipelines. These merchandises have to be transported throughout the world via pipeline networks. It is obvious that modern economy relies on these networks of pipelines that are distributed over hundreds of miles throughout many areas around the world. Unfortunately these pipelines run through harsh environments resulting in many problems. Among those are leakage problems. “According to the US Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA), 25% of all pipeline failure incidents reported in the US from 2002 to 2003 were caused by corrosion (leakage main cause)” [8].

The consequences of leakage can be more than the financial issues. It can affect people’s lives and the environment. In the oil industry, these consequences are more noticeable where leaks in pipelines may cause disastrous consequences that can last for years. For oil and gas companies, pipeline leaks are one of the major causes of failure because of their significant length in remote and harsh areas. This latest, is prompting the need of lots research to be done in order to prevent corrosion. Therefore, in this study we are focusing on enhancing the performance of the ICCP in order to build strong system against corrosion to save people life as well as the environment.

1.4 Problem Statement

The potential required for impressed current cathodic protection depends upon the steel being protected from its environment. Output voltage, depending on desired reference voltage, needs to be controlled and tuned by transformer rectifier (TR) units of the CP Stations.

Basically, TR unit with high output voltage requires high performance control to maintain the correct output voltage. Moreover, applying the classical control or fuzzy logic control based on trail and error and/or training data for the ICCP systems have shown significant overshoot and oscillation in the output potential. For thes reasons, more works regarding the tuning of the output of TR units are needed to achieve better accuracy and performance.

1.5 Project Objectives

1. To build an effective laboratory scale for the Impressed Current Cathodic Protection (ICCP) system.
2. To obtain a parametric model for the ICCP system.
3. To design, simulate and experiment self-tuning adaptive controller for an ICCP systems.

1.6 The Project Scope

The scope of this project is to study the impressed current cathodic protection (ICCP) system and its concepts in preventing the external corrosion of underground carbon steel pipelines. Then, experimental works will be carried out to build an effective laboratory scale for ICCP systems. The system would be used for black box identification so that system identification approach will be used to obtain the mathematical model which represents the ICCP systems. After that, direct self-tuning generalized minimum variance control would be used to design an adaptive corrosion controller for this system as well. Finally, experimental work would be carried out to test the performance of the designed controller.

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