Ain Shams University
Faculty of Engineering
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Applications of Phasor Measurement Units (PMUs) in Power System Protection

Ph.D. Thesis

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Submitted in partial fulfillment of the requirements for the Ph.D. degree in Electrical Engineering

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STATEMENT

This Thesis is submitted to Ain Shams University in partial fulfillment of the requirements for PhD. degree in Electrical Engineering.

The included work in this thesis has been carried out by the author at the department of electrical power and machines, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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ABSTRACT

A reliable, continuous supply of electric energy is essential for the functioning of today's modern complex and advanced society. Electricity is one of the prime factors of the growth. It determines the value of the society.

The Phasor Measurement Unit (PMU) is considered to be one of the most important measuring devices in the field of power systems protection. The distinction comes from its unique ability to provide synchronized phasor measurements of voltages and currents from widely dispersed locations in an electric power grid. The commercialization of the Global Positioning Systems (GPS) with accuracy of timing pulses in the order of 1 microsecond allowed for the commercial production of phasor measurement units.

This thesis presents a protection scheme used for detection of single line outage in a transmission network using Support Vector Machine (SVM). The classification task is performed for each line in the network using parallel processing, where the state of each line is determined by an individual SVM.

The proposed technique has been trained and tested through computer simulation studies for a typical 14-bus and 30-bus IEEE network models implemented in PSCAD/EMTDC package. The PMUs calculations use Rockefeller and Udren algorithm to calculate the buses phase angles that are a basic factor used in detection of outaged line as they change according to the power flow change followed by the line outage. The SVMs are trained with different kernel functions with different parameter values to get the most optimized model.

Another protection application of PMUs, which is the fault location of both uncompensated and series compensated transmission lines, is also

investigated in the thesis. The performance of the proposed method is investigated using PSCAD/EMTDC simulation package with the aid of MATLAB programming tool.

In addition, a fault location of series compensated transmission line is studied for both types of series compensation (i.e. compensation in the middle of the line and compensation at both ends).

Two proposed approaches are tested; one using voltage measurements only and the other considers both voltage and current measurements. Accuracies are calculated and compared to evaluate the most accurate one.

The computer simulation does not exactly match the field data because the incoming data are affected by the transducers and environmental noise. Therefore, the proposed technique is also tested with superimposed noise test data. Then, it is tested again with superimposed error in line parameters evaluation. This ensures the robustness of the proposed algorithm.

The results presented in this thesis confirm the feasibility of the proposed protection schemes.

The thesis consists of six chapters

Chapter (1): Gives an introduction to PMUs.

Chapter (2): Introduces a literature survey of most protection applications of PMUs.

Chapter (3): presents a study of SVM as a classification tool used in line outage detection.

Chapter (4): Shows a numerical simulation for line outage studies.

Chapter (5): Introduces a numerical simulation for fault location studies.

Chapter (6): presents the extracted conclusions and future work suggestions.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANN	Artificial Neural Network
CT	Current Transformer
DC	Direct Current
DFT	Discrete Fourier Transform
DG	Distributed Generation
DT	Decision Tree
EHV	Extra High Voltage
ERM	Empirical Risk Minimization
FACTS	Flexible Alternating Current Transmission Systems
FHRCNN	Fuzzy Hyper-Rectangular Composite Neural Networks
FT	Fourier Transform
GPS	Global Positioning Systems
HVDC	High Voltage Direct Current
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
KHS	Kernel Hilbert Spaces
KTT	Karush-Kuhn-Tucker
LPC	Local Protection Center
MOV	Metal Oxide Varistor
PI	Performance Indices
PMU	Phasor Measurement Unit
PSCAD	Power System Computer Aided Design
QP	Quadratic Programming
RBF	Radial Basis Function
RFC	Remote Feedback Controller
ROCOF	Rate Of Change Of Frequency
SC	Series Compensation
SCADA	Supervisory Control And Data Acquisition
SDFT	Smart Discrete Fourier Transform
SPC	System Protection Center
SRM	Structural Risk Minimization
SVC	Static Var Compensator
SVM	Support Vector Machine
TSCS	Thyristor Controlled Switched Capacitor
TVE	Total Vectorized Errors
UHV	Ultra High Voltage
VC	Vapnik - Chervonenkis
VSM	Voltage Security Monitoring
WAMS	Wide Area Monitoring Systems

Chapter 1

INTRODUCTION

1.1 GENERAL

In the last few decades, much research work has been concentrating on the exploration and introduction of Global Positioning Systems (GPS) facilities. It is a group of satellites which is placed into space orbits capable to position data to locate anything on Earth. The satellites transmit timing signals and position data. GPS was used in geographical and military applications. Then, it was utilized in navigation and agricultural applications. Now, in engineering applications, GPS are continually spreading in civil engineering applications, in communication, and in electric power applications.

Due to the correlation between Phasor Measurement Units (PMUs) and the GPS, PMUs began to spread widely after the great improvement in the satellite techniques and communications. Nowadays, PMU is one of the most important units in the applications of modern power systems and attractive measuring devices for the electrical engineering researches.

This chapter presents an introduction including an overview of the PMU, fields of applications of the PMU and the use of PMU in power system protection. The objectives and contributions are stated. Finally, thesis outlines are cleared.

1.2 PMU OVERVIEW

Phasor is a quantity with a magnitude and phase (with respect to a reference) that is used to present a sinusoidal signal as shown in Fig. 1.1.