FAULT ZONE DISCRIMINATION AND FAULT LOCATION FOR SERIES FACTS-BASED TRANSMISSION LINES

By

Ahmed Nasr Zeinhom Hassan

A thesis submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

Electrical Power and Machines Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2016

FAULT ZONE DISCRIMINATION AND FAULT LOCATION FOR SERIES FACTS-BASED TRANSMISSION LINES

By

Ahmed Nasr Zeinhom Hassan

A thesis submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

Electrical Power and Machines Engineering

Under supervision of

Prof. Dr. Mahmoud Ibrahim Gilany

Electrical Power and Machines Department

Faculty of Engineering,

Cairo University

Associate Prof. Dr. Doaa Khalil Ibrahim

Electrical Power and Machines Department

Faculty of Engineering,

Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2016

FAULT ZONE DISCRIMINATION AND FAULT LOCATION FOR SERIES FACTS-BASED TRANSMISSION LINES

By

Ahmed Nasr Zeinhom Hassan

A thesis submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

Electrical Power and Machines Engineering

Approved by the
Examining Committee

Prof. Dr. Mahmoud Ibrahim Gilany Main Supervisor

Prof. Dr. Hany Mohamad Amin Elghazaly Internal Examiner

Prof. Dr. Mohamed Mostafa Sallam External Examiner
Faculty of Engineering – Helwan University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2016

ACKNOWLEDGMENTS

First of all, thanks to Allah who supported and strengthened me in all of my life and in completing my studies for the Master of Science (M.Sc.) degree.

I would like deeply to express my thanks and gratitude to my supervisors; Prof. Dr. Mahmoud Gilany and Associate Prof. Dr. Doaa Khalil Ibrahim, Electrical Power and Machines Department, Faculty of Engineering, Cairo University for their faithful supervision, enormous efforts, and their great patience during the period of the research.

Also, I would like to thank all my fellow colleagues for their support to me. I want also to express thanks to Eng. Ahmed Amin for his important advices during my work. Also, I don't want to forget my supervisors at DAR Engineering; Eng. Mansour Hussein, Eng. Mohamed Mostafa, and Eng. Ahmed Rashed for their great support during my study.

Moreover, I would like to thank MathWorks for their valuable support with student and trial versions of MATLAB/SIMULINK software package.

Finally, I would like to thank my family for their great inspiration, kind support, and continuous encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

• Symbols

Δt	Travelling wave reflection time difference in seconds
I_F	Fault current in kA
I_{F1}	Left-hand side component of fault current in kA
I_{F2}	Right-hand side component of fault current in kA
I_M	Fundamental-frequency positive-sequence current at terminal M in Volt
I_R	Fundamental-frequency positive-sequence current at terminal R in Volt
I_S	Fundamental-frequency positive-sequence current at terminal S in kV
K_{SE}	Degree of Series Compensation in %
L	Total line length (either S–M or M–R) in km
R_F	Fault resistance in Ω
V_F	Fault voltage in kV
V_M	Fundamental-frequency positive-sequence voltage at terminal M in kV
V_R	Fundamental-frequency positive-sequence voltage at terminal R in kV
V_S	Fundamental-frequency positive-sequence voltage at terminal S in kV
x	Fault location in km
X_C	Series compensation reactance in Ω
y	Transmission line shunt admittance per unit length in Mho/km
z	Transmission line series impedance per unit length in Ω/km
Z_0	Surge impedance in Ω
γ	Propagation constant in rad./km

• Abbreviations

AC	Alternating Current
DWT	Discrete Wavelet Transform
EHV	Extra High Voltage
FACTS	Flexible Alternating Current Transmission Systems
FFT	Fast Fourier Transform
FPFM	Feeder Protection First Main
FPSM	Feeder Protection Second Main
FSC	Fixed Series Compensation
GCSC	GTO Thyristor-Controlled Series Capacitor
GPS	Global Positioning System
HVDC	High Voltage Direct Current
IED	Intelligent Electronic Device
MOV	Metal-Oxide varistor
MSC	Mechanically-Switched Capacitor
PMU	Phasor Measurement Unit
RCA	Relay Characteristic Angle
SEC	Saudi Electricity Company
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
SVM	Support Vector Machine
TCR	Thyristor-Controlled Reactor
TCSC	Thyristor-Controlled Series Capacitor

TCSR	Thyristor-Controlled Series Reactor
TDNN	Time-Delayed Neural Network
TSC	Thyristor-Switched Capacitor
TSR	Thyristor-Switched Reactor
TSSC	Thyristor-Switched Series Capacitor
TSSR	Thyristor-Switched Series Reactor
UHV	Ultra High Voltage
UPFC	Unified Power Flow Controller

ABSTRACT

Discrimination and location of faults in Flexible Alternating Current Transmission Systems (FACTS) have several challenges in modern power systems. This is because of the errors in the measured impedance as a result of the changes caused by FACTS' controllers to improve the power system performance. The presence of series FACTS device in a transmission line complicates both the fault location and the discrimination procedure between faults in front of and behind and the FACTS device.

This thesis proposes an integrated solution for both fault zone discrimination (either in front of or behind the FACTS device) and fault location for series FACTS-compensated transmission lines. In the proposed algorithm, online calculations of the exact series-compensated line parameters are carried out continuously in normal conditions (pre-fault calculations) to estimate the actual percentage of compensation. After fault inception, a wavelet-based subroutine is applied to decide whether the fault is in front of the FACTS device or behind it. Then, a conventional distance protection algorithm is used to estimate the fault zone. Finally, synchronized data signals from both ends are used to accurately locate the exact fault location offline.

The complete algorithm is tested using a real data for a 380 kV, 400 km series-compensated transmission line in Saudi Arabia using MATLAB/SIMULINK. Different types of grounded and ungrounded faults, fault locations, fault resistances, fault inception angles, series FACTS types, compensation levels, power transfer angles, and synchronization errors are applied to validate the effectiveness of the proposed algorithm. Metal-Oxide Varistor (MOV) nonlinear operation is also taken into account. Extensive simulation results show the effectiveness and robustness of the proposed algorithm.

CHAPTER (1): INTRODUCTION

1.1. Background

Fast-growing electrical power demand is a challenge that faces almost all power systems all over the world. In order to meet the steadily increasing electrical power demand, large investments are required to construct new generation, transmission, and distribution facilities. This economical constraint is added to the right of way constrains which limit the ability of the power system expansion. Accordingly, the gap between the increasing electrical power demand and the available electrical power generation increases which in-turn affects the system stability and the continuity of supply.

As a result of that increasing in the electrical power demand, Flexible Alternating Current Transmission Systems (FACTS) are introduced in modern power systems as powerful techniques to improve the power system performance. These FACTS techniques are used extensively in modern Extra High Voltage (EHV) and Ultra High Voltage (UHV) transmission systems in order to avoid or postpone the construction of new lines and to cope with the fast-growing electrical power demand.

The Institute of Electrical and Electronics Engineers (IEEE) defines the FACTS as "a power electronic based system and other static equipment that provide control of one or more alternating current transmission system parameters to enhance controllability and increase power transmission capability" [1]. As the power transfer on an alternating current (AC) transmission system is restricted by thermal limit, voltage stability, and transient stability limits, the role of the FACTS devices is to control the power system parameters in order to raise both the voltage stability and transient stability limits, which allow for higher power transfer and better system operability [2]. The main applications of FACTS devices in modern power systems are summarized as follows [2], [3], [4]:

- Boosting of power transfer capability,
- Reactive power compensation,
- Power flow control,
- Voltage control,
- Improvement of power factor,
- Improvement of transient stability,
- Improvement of power quality,
- Interconnection of renewable energy and other distributed generation resources.