اية

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

(اللَّهُ نُورُ السَّمَاوَاتِ وَالْأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ
الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ
شَجَرَةٍ مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ
وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ
وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيم) ﴿٣٥﴾ .

صدق الله العظيم

سورة النور الاية (٣٥)

Dedication

To whom my words are not enough to expiree my deep indebtedness, thanks and gratefulness.

To my father soul and my mother, the sustainable source of tenderness, kindness and endless support and specific.

My dedication also extends to my brothers, sisters, colleagues, friends, relatives, and teachers

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Abstract

The requirement for reliability and security in power system is increasing every day with the increase in complexity of the power system networks. In order to ensure highest level of reliability and protection, relays have to receive correct and accurate measurement values. Conventionally, currents and voltages in protection system are measured using inductive-type instrument transformers. Due to their design, conventional instrument transformers introduce distortions to the current and voltage signal replicas, which may cause mal-operation of protective relays.

The aim of this thesis is to develop new optical fiber current transformer (OFCT). The performance of power system protection is evaluated using an OFCT instead of conventional CT through dynamic simulation studies. Additionally, the thesis focuses into development of an experimental model of an OFCT, and investigation of its application in power system protection.

Derivations a mathematical model of the optical fiber current transformer from its principles of operation indicating the various detection configurations provided. Various assumptions are taken into considerations to reduce the complexity of the OFCTs model whilst maintaining an acceptable level of accuracy of dynamic performance of OFCTs. Jonse Matrix is used to redesign the OFCT with Faraday Rotation Mirror to eliminate linear birefringence and other effects.

Multifunction numerical relay model is developed including fault detection algorithms. The operating performance of the numerical relay with OFCT is evaluated using various simulation scenarios based on operating characteristic, and trip-times. The simulation evaluation is carried-out using MATLAB / SIMULINK.

An experimental model is configured to implement and test the OFCT, the numerical relay is implemented using PIC16F877A microcontroller. The simulation and experimental results prove that OFCTs are capable to measure current with very high accuracy over wide dynamic range with acceptable errors that match the IEC 0.2 class accuracy requirements. Furthermore, OFCTs has extraordinary features, which makes it more suitable for replacing conventional CTs. Additionally, OFCTs are providing direct to digital outputs according to the IEC 61850 standard, these outputs are immediately compatible with modern digital substation communication.

المستخلص

تزايد متطلبات الموثوقية والأمان في نظم االقدرة الكهربائية كل يوم مع زيادة تعقيد شبكات نظم القدرة. من أجل ضمان أعلى مستوى من الموثوقية يجب أن تتغذي مرحلات الحماية بقيم مقياسة دقيقة وصحيحة. تقليديا، يتم قياس التيارات والجهود في نظم حماية القدرة الكهربائية بإستخدام محولات التيار و الجهد التقليدية المبنية علي اساس الحث الكهرومنغاطيسي. بناءاً علي تصميمها، تظهر محولات القياس التقليدية بعض التشويهات لإشارات التيار والجهد التي قد تتسبب في تشغيل خاطئ لمرحلات الحماية.

يهدف هذا البحث لتصميم وتطوير محول تيارالالياف بصرية (OFCT) وإستخدامه في منظومة الحماية لنظم القدرة الكهربائية. تم تقييم أداء حماية القدرة الكهربائية باستخدام محولات تيار الالياف بصرية OFCT بدلاً من محولات التيار التقليدية من خلال دراسات المحاكاة الديناميكية. بالإضافة إلى ذلك، يركز هذا البحث على تطوير نموذج مختبري لمحول تيار الالياف البصرية والتحقق من تطبيقه في حماية نظم االقدرة الكهربائية.

أشتق النموذج الرياضي لمكونات محول تيار الالياف البصرية من خلال مبادئ التشغيل وهيئات كشف الاشارة المختلفة. أخذت في الاعتبار بعض الإفتراضات لتقليل تعقيد نموذج محول تيار الالياف البصرية مع الحفاظ على مستوى مقبول من الدقة للأداء الديناميكي.

أستخدمت مصفوفات جونس(Jonse Matrix) لإعادة تصميم محول تيار الالياف البصرية مع مرآة دوران فاراداي للقضاء على تاثير ثنائية الانكسار الخطي والتأثيرات البصرية الأخرى. تم تطوير نموذج المرحل العددي متعدد الوظائف بما في ذلك خوارزميات إكتشاف الاعطال الكهربائية.

تم تقييم الأداء التشغيلي لمرحل الحماية العددي مع محول تيار الالياف البصرية باستخدام سيناريوهات محاكاة مختلفة على أساس خصائص التشغيل وزمن إشارة الفصل للمرحل. ثم نفذ تقييم المحاكاة باستخدام MATLAB M-files و SIMULINK. تم بناء نموذج مختبري لتنفيذ واختبار محول تيار الالياف البصرية ، وكذلك بناء و تنفيذ المرحل العددي باستخدام المتحكم الدقيق PIC16F877A. اثبتت نتائج نموذح المحاكاة والنتائج المعملية أن محولات تيار الالياف البصرية قادرة على قياس التيار بدقة عالية جدًا عبر نطاق ديناميكي عريض مع أخطاء مقبولة تتطابق مع متطلبات دقة فئة IEC 0.2. بالإضافة إلى ذلك ، لدى محولات تيار الالياف البصرية ميزات فائقة، مما يجعلها أكثر ملاءمة لاستبدال محولات التيار التقليدية. علاوة على ذلك ، توفر محول تيار الالياف البصرية مخرجات رقمية وفقًا لمعيار IEC 61850، مما يجعل هذه المخرجات متوافقة مع نظام الاتصالات الرقمية في المحطات الفرعية الحديثة.

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List of Symbols

N_u	a transformation ratio of the CVT
I	light beam intensity [w/ m^2]
ω	angular frequency [rad/s]
φ	angle of state of polarization [rad]
$\boldsymbol{V}$	Verdet constant
B	magnetic flux density vector [tesla]
f	Frequency [Hz]
λ	wavelength
n	refractive index
N_F	number of turns of sensing optical fiber loop
$I_{\boldsymbol{elec}}$	electrical current in conductor [A]
$i(t)$	laser current [mA]
L	inductance [H]
S(t)	photon density [m^{-3}]
Γ	optical confinement factor
g_o	slope gain [cm^{-3}/s]
N(t)	carrier density [m^{-3}],
N_o	carrier density at transparency [cm^{-3}]
τ_n	carrier lifetime
V_a	volume of the active region[cm^3]
$\phi(t)$	phase of the laser electric field [rad]
$P(t)$	Laser diode optical output power [w]
υ	frequency of the laser [s^{-1}]
τ_n	carrier lifetime
η	total quantum efficiency
$n(\lambda)$	refraction index t a given wavelength,
λ_0	initial wavelength.
$V(\lambda)$	Verdet constant as function of wavelength [rad/tesla.m]
$\alpha(L)$	attenuation coefficient of function of fiber length [dB/km]
$\alpha(\lambda)$	attenuation coefficient due to Rayleigh scattering [dB/km]

E	Electric Field
ϕ	phase shift due to the circular birefringence [rad]
δ	phase shift due to linear birefringence [rad]
Δ	geometric mean of phase shifts
J	Jones vector of optical component
$\mathcal{R}(\lambda)$	responsivity of photodetector as function of wavelength [A/W].
I_P	photocurrent
$\mathrm{D_C}$	diameter of the fiber sensing coil [m].
c	Speed of light [m/s]
l	Length of optical path [m]
k	Wavenumber of light wave [m^{-1}]
τ	optical fiber sensing coil transit time of optical signal.
γ	electro-optic coefficient
μ_o	Permeability of free space [H/m]
ε_o	Permittivity of free space [F/m]
TMS	time multiplier setting
t	operating time [s]
I_s	overcurrent setting [A]
K	Residual compensation factor
Z_O	Zero-sequence impedance [Ω]
Z_1	Positive-sequence impedance [Ω]
I_a, I_b, I_c	current phases [A]
V_{an}, V_{bn}, V_{cn}	voltage phases [V]
R	Resistance [Ω]
X	reactance [Ω]
C	Capacitive [F]

List of Abbreviations

A, B, C	phase A, phase B, phase C
ABB	ABB Asea Brown Boveri
AF	Analog Filter
ADC	Analog to Digital Converter
ALU	Arithmetic Logic Unit
ANN	Artificial Neural Networks
BW	Band Width
BS	Beam Splitter
CCVT	Coupling Capacitor Voltage Transformers
CSI	Current Source Inverter
CT	Current Transformer
DAQ	Data Acquisition
DFT	Discrete Fourier Transform
DSP	Digital Signal Processor
DC	Direct Current
EMI	Electromagnetic Interference
emf	Electromotive Force
ECT	Electronic Current Transformer
EMTP/ATP	Electromagnetic Transients Program
EOVT	Electro-optic Voltage Transducer
EVT	Electronic Voltage Transformer
FP	Fabry-Pérot
FRM	Faraday Rotator Mirror
FFT	Fast Fourier Transform
FBG	Fiber Bragg Grating
FPGA	Field Programmable Gate Array
FR	Frequency Response
GPS	Global Positioning System
HV	High Voltage
HB	Highly Birefringent

ICD	In Circuit Debug
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IT	Instrument Transformer
IED	Intelligence Electronic Device
IDMT	Inverse Definite Minimum Time
LDR	Light Dependent Resistors
LED	Light Emitting Diode
LCD	Liquid Crystal Display
LV	Low Voltage
MOCT	Magneto-optical Current Transformer
MU	Merging Unit
NCIT	Non-conventional Instrument Transformer
NPR	Numerical Protective Relays
NXCT	NxtPhase Current Transformer
NXVCT	NxtPhase Voltage and Current Transformer
NXVT	NxtPhase Voltage Transformer
OCT	Optical Current Transformer
OFCT	Optical Fiber Current Transformer
OHL	Overhead Lines
OIT	Optical Instrument Transformer
OVT	Optical Voltage Transformer
OE	Optoelectronic
OCR	Overcurrent Relay
PD	Photodetector
PBS	Polarizing Beam Splitter
PC	Polarization Controller
PDL	Polarization Dependent Loss
PMF	Polarization Maintaining Fiber
PMUs	Phasor measurement units
PIC	Programmable Interrupt Controller

PST	phase-shifting transformer
RAM	Random Access Memory
ROM	Read only Memory
RISC	Reduced Instruction Set Computing
RCCT	Rogowski Coil Current Transducer
RMS	Root Mean Square
SNR	Signal to Noise Ratio
SLGF	Single Line to Ground Fault
SMF	Single Mode Fiber
SOP	State of Polarization
UGC	underground cable
UHV	Ultra High voltage
WP	Wollaston Prism