PARTIAL DISCHARGE DETECTION AND LOCATION TECHNIQUE BASED ON SEGMENTED CORRELATION TRIMMED MEAN ALGORITHM FOR POWER CABLE

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UNIVERSITI MALAYSIA PERLIS

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PARTIAL DISCHARGE DETECTION AND LOCATION TECHNIQUE BASED ON SEGMENTED CORRELATION TRIMMED MEAN ALGORITHM FOR POWER CABLE

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
ADC	Analog to digital converter
AM	Amplitude modulation
DOP	Damped oscillating pulse
DSI	Discrete spectral interference
DWT	Discrete wavelet transform
EMI	Electromagnetic interference
EPR	Ethylene propylene rubber
FM	Frequency modulation
GMR	Giant magneto resistive
GPS	Global Positioning System
HF	High-pass filter
HFCT	High frequency current transformer
IOT	Internet of things
LF	Low-pass filter
MATLAB	Matrix laboratory
MEC	Multi-end correlation
MI	Magneto impedance
MV	Medium voltage
PD	Partial discharge
RC	Rogowski coil
SC	Segmented correlation
SCTM	Segmented correlation trimmed mean
TDA	Time difference of arrival

TDR	Time domain reflectometry
UHF	Ultra-high frequency
UWB	Ultra-wide band
WGN	White Gaussian noise
XLPE	Cross-linked polyethylene

LIST OF SYMBOLS

ε	Effective relative permittivity
ν	Propagation velocity in the cable
φ	Angle (rad.)
Ω	Resistance (ohm)
μ_0	Air permeability
A	Magnitude coefficient
A_i	Multiple magnitude coefficient
$A_{injected}$	Magnitude of injected signal
$A_{measured}$	Magnitude of measured signal
$A[n]$	Measured signal of RC sensor at point *A*
$B[n]$	Measured signal of RC sensor at point *B*
bior	Biorsplines
$C[n]$	Measured signal of RC sensor at point *C*
coif	Coiflets
CR_{BA}	Correlation factor of sampling window *A* and sampling window *B*
db	Daubechies
f_i	Multiple frequencies
h	Height
IQR	Interquartile range
k	Class interval
L	Length of monitoring cable
L_A	PD travelling distance from PD source to point *A*
L_B	PD travelling distance from PD source to point *B*
L_C	PD travelling distance from PD source to point *C*

m	Total number of samples that enter the mod class
M_c	Mutual inductance
N	Number of winding turns
N_s	Sampling numbers
$NFCF_{max}$	Number of shifted samples that gives the maximum full correlation factor
$NSCF_{max}$	Number of shifted samples that gives the maximum segmented correlation factor
Q_1	First quartile
Q_3	Third quartile
rbio	Reverse biorsplines
R_{in}	Inner radius
R_{out}	Outer radius
S_{max}	Maximum estimated PD location values
S_{min}	Minimum estimated PD location values
S_n	Estimated PD location values that enter the mod class
SCF_{AB}	Segmented correlation factor of signal *A[n]* and signal *B[n]*
SCF_{CB}	Segmented correlation factor of signal *C[n]* and signal *B[n]*
SS	Shifted samples
SSO_{max}	Numbers of samples in adjacent signal that gives a maximum peak
SSR_{max}	Numbers of samples in reference signal that gives a maximum peak
sym	Symlets
t	Time
T_A	PD arrival time at point *A*
T_B	PD arrival time at point *B*
T_C	PD arrival time at point *C*
T_p	Program execution time

TD_{AB}	Time difference between signal *A[n]* and signal *B[n]*
TD_{CB}	Time difference between signal *C[n]* and signal *B[n]*
TSR	Total samples of reference signal before the signal was cropped
$TSR_{cropped}$	Total samples of reference signal after the signal was cropped
V_{loss}	Voltage loss
$V_{injected}$	Injected voltage
$V_{measured}$	Measured voltage
V_s	Propagation velocity in free space
w_d	Angular frequency

TEKNIK PENGESAN DAN LOKASI PELEPASAN CAS SEPARA BERDASARKAN ALGORITMA KORELASI BERSEGMEN POTONGAN PURATA UNTUK KABEL KUASA

ABSTRAK

Kabel kuasa mungkin mengalami kelemahan pada penebat selepas tempoh masa tertentu kerana faktor persekitaran, mekanikal dan elektrik. Pelepasan cas separa pada kekosongan atau rongga penebat kabel kuasa akan membawa kepada gangguan sistem kuasa dalam masa terdekat. Pada masa ini, banyak peranti lokasi pelepasan cas separa telah dicipta untuk menganggarkan lokasi pelepasan cas separa pada kabel kuasa. Teknologi baru telah membolehkan anggaran pelepasan cas separa dilaksanakan dari anggaran pelepasan cas separa talian mati ke anggaran pelepasan cas separa talian hidup. Teknik pemprosesan isyarat maju boleh diaplikasikan ke dalam peranti tersebut untuk menganggarkan lokasi pelepasan cas separa dengan lebih tepat. Di dalam tesis ini, algoritma korelasi bersegmen potongan purata dicadangkan untuk menganggarkan lokasi pelepasan cas separa pada kabel kuasa voltan sederhana. Algoritma ini menggunakan teknik korelasi bersegmen dan teknik penapisan data potongan purata untuk meningkatkan ketepatan lokasi anggaran pelepasan cas separa. Dua eksperimen telah dilakukan untuk menguji masa pelaksanaan program dan ketepatan algoritma terhadap gangguan. Algoritma telah diuji dalam persekitaran MATLAB yang terdiri daripada isyarat pelepasan cas separa yang dimodelkan dan pelbagai tahap gangguan Gaussian putih dan gangguan spektrum diskret. Teknik transformasi wavelet diskret telah digunakan untuk penapisan gangguan. Eksperimen pertama dilakukan dengan meningkatkan bilangan pensampelan yang diukur sementara mencatat masa pelaksanaan program algoritma. Eksperimen kedua dilakukan dengan meningkatkan tahap gangguan Gaussian putih dan gangguan spektrum diskret sementara mencatat ralat peratusan maksimum anggaran lokasi pelepasan cas separa. Hasil dari kedua-dua eksperimen ini dibandingkan dengan algoritma korelasi pelbagai hujung yang sedia ada. Hasilnya menunjukkan bahawa algoritma korelasi bersegmen potongan purata memerlukan program perlaksanaan masa yang lebih panjang tetapi ralat peratusan maksimum anggaran lokasi pelepasan cas separa yang lebih rendah daripada algoritma korelasi pelbagai hujung. Kesimpulannya, algoritma korelasi bersegmen potongan purata lebih sesuai digunakan dalam sistem anggaran lokasi pelepasan cas separa kerana ia mempunyai ralat peratusan maksimum anggaran lokasi pelepasan cas separa yang lebih rendah.

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ABSTRACT

Power cable may suffer from insulation degradation after a certain period of time because of environment, mechanical and electrical factors. Partial discharge (PD) at void or cavity of power cable's insulation will lead to the power system breakdown in the near future. Nowadays, many PD location devices had been invented to estimate PD location on power cable. New technology has enabled PD estimation to evolve from offline PD estimation to online PD estimation. Advanced signal processing technique can be implemented in those devices in order to estimate PD location accurately. In this thesis, segmented correlation trimmed mean (SCTM) algorithm is proposed to estimate PD location on medium voltage (MV) power cable. The algorithm uses segmented correlation technique and trimmed mean data filtering technique to enhance the accuracy of the estimated PD location. Two experiments have been performed to test the program execution time and accuracy against noise of the algorithm. The algorithm had been tested in Matrix Laboratory (MATLAB) environment which consists modelled PD signals and different levels of white Gaussian noise (WGN) and discrete spectral interference (DSI). Discrete wavelet transform (DWT) de-nosing technique has been used for noise suppression. The first experiment is performed by increasing the sampling number of measured signal while recording the program execution time of the algorithm. The second experiment is performed by increasing the level of WGN and DSI while recording the maximum percentage error of the estimated PD location. The results from both experiments are compared with the existing multi-end correlation (MEC) algorithm. The results shown that the SCTM algorithm has longer time but lower maximum percentage error of the estimated PD location than MEC algorithm. In conclusion, SCTM algorithm is more suitable to apply in PD location estimation system for power cable due to its lower maximum percentage error.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Cross-linked polyethylene (XLPE) insulated power cable has been widely used in medium voltage (MV) distribution line because of its good insulating properties such as high electrical resistance and mechanical strength, high-aging and environmental stress resistance, higher operating time under long term temperature as well as being anti-corrosive in nature (Yuan et al., 2013; Permal, Chakrabarty, A.R, Marie, & Abd Halim, 2016). However insulation degradation of power cable will be boosted due to electric field, thermal effect, mechanical stress, chemical corrosion, environment condition and manufacturing defects (Densley, 2001). The possible aging mechanisms of cable insulation system is listed in Table 1.1.

According to the report of performance and statistical information electricity supply industry in Malaysia 2014 as shown in Table 1.2, cable and joint fault was the main cause of the unscheduled supply interruption, which had gone up to a significant 74.14% (Energy Commission of Malaysia, 2015). Insulation degradation of power cable is one of the factor contributes to the fault occurs at cable and joint. Unscheduled supply interruptions have catastrophic impact to industries and hospitals because these fields require high reliability of electrical energy supply to prevent damage on expensive machines and interruptions in surgical operations. Besides that, electrical energy suppliers will lose millions of Ringgit Malaysia due to unscheduled supply interruptions to the power system. Therefore, unscheduled supply interruption problem of cable and joint ought to be overcome in order to increase the reliability of electrical energy supply.

Table 1.1: Possible aging mechanisms of cable insulation system (Densley, 2001).

Ageing Factor	**Ageing Mechanisms**	**Effects**
Thermal		
-High temperature -Temperature cycling	-Chemical reaction -Incompatibility of materials -Thermal expansion (radial and axial) -Diffusion -Anneal locked-in mechanical stresses -Melting/flow of insulation	-Hardening, softening, loss of mechanical strength, embattlement -Increase tan delta -Shrinkage, loss of adhesion, separation, delamination at interfaces -Swelling -Loss of liquids, gases -Conductor penetration -Rotation of cable -Formation of soft spots, wrinkles -Increase migration of components
-Low temperature	-Cracking -Thermal contraction	-Shrinkage, loss of adhesion, separation, delamination at interfaces -Loss/ingress of liquids, gases -Movement of joints, terminations
Electrical		
-Voltage, ac, dc. -Impulse	-PD -Electrical treeing (ET) -Water treeing (WT) -Dielectric losses and capacitance -Charge injection -Intrinsic breakdown	-Erosion of insulation → ET -PD -Increased losses and ET -Increased temperature, thermal ageing, thermal runaway -Immediate failure
-Current	-Overheating	-Increased temperature, thermal ageing, thermal runway
Mechanical		
-Tebsile, compressive, shear stresses -Fatigue, cycle bending, vibration	-Yielding of materials -Cracking -Rupture	-Mechanical rupture - Loss of adhesion, separation, delamination at interfaces -Loss/ingress of liquids, gases
Environmental		
-Water/humidity -Liquids/gases -Contamination	-Dielectric losses and capacitance -Electrical tracking -Water treeing -Corrosion	-Increased temperature, thermal ageing, thermal runaway -Increased losses and ET -Flashover
Radiation	-Increase chemical reaction rate	-Hardening, softening, loss of mechanical strength, embattlement
*The failure mechanism is usually electrical. eg., by PD, ET or tracking		

Table 1.2: Percentage of unscheduled supply interruptions by type of interruptions for MV distribution line (Energy Commission of Malaysia, 2015).

Category	Total	Percentage (%)
Cable & Joint	6348	74.14
Third party	841	9.82
Natural disaster	355	4.15
Faulty equipment	325	3.80
Others	693	8.09

Partial discharge (PD) diagnosis on power cable is proven to reduce the unscheduled supply interruptions and it is a routine test performed by the electric energy supplier. PD is a localized dielectric breakdown of a small portion of cable's insulation, which causes repetitive small amplitude signal to travel along the cable's conductor. In other words, PD resembles cancer in insulated cable before fault happens (Cselkó & Berta, 2013). Before this, the PD diagnosis on power cable is done manually. The inspection is done once a year as PD diagnosis can cause an interruption to the inspected power cable. Thus, several smart power line systems were proposed by many previous researchers for on-line monitoring and estimating of the PD location on power lines (M. Tang, Li, Liu, & Liang, 2013).

Figure 1.1 shows the schematic diagram of proposed on-line multi-end PD location estimation system for PD detection and location in MV distribution power cable. PD sensors are mounted 2.5 m apart at node A, B and C to measure PD arrival signals from a PD source in an power cable. The measured signals are synchronized by using Global Positioning System (GPS) time update system and transmitted to main unit at substation by using internet of things (IOT) for PD location.