University of Technology, Sydney

Faculty of Engineering

Fault Location and Forewarning On Transmission Systems Using Travelling Wave Transients

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Statement of Authorship & Originality

I certify that this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been entirely written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Production Note:
Signature removed prior to publication.

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Abstract

This thesis examines the main circuit modelling fundamentals and fault location techniques that may be applied to electricity transmission networks. Using a statistical comparison, it then investigates both impedance and travelling wave based fault location methods. This appears to be a novel comparison as no publications have been identified which draw conclusions on the accuracy of these fault location techniques. This work subsequently led TransGrid to install a new commercial travelling wave fault location system on the New South Wales 330kV transmission network.

Following the commissioning of this system, there was an ongoing process to store data that was being observed by the travelling wave recorders. This data was later cross-referenced to determine the fault location, and the waveform interpreted to identify the source of the travelling wave transient. However, this analysis has revealed that the theoretical accuracy of this travelling wave system was not as good as previously expected from publication.

The source of the degradation was tracked down and found to centre on the frequency response of the coupling transducers used by most conventional travelling wave recording hardware. These errors are not currently considered in publication but can result in several kilometres of uncertainty in a fault location calculation. Hence, it can be concluded that the use of conventional substation current transducers can introduce additional uncertainty into travelling wave fault location calculations.

The source and nature of this uncertainty has subsequently led to the development of a novel unsynchronised fault location algorithm based on the continuous wavelet transform. This new technique also uses an assessment of waveform polarity to distinguish between signals generated by solid or incipient line faults.

Several unusual events have also been observed which have led to a number of new developments in fault location and forewarning. These include specific requirements for impedance algorithms during unearthed inter-circuit faults on double circuit lines.

Similarly, this thesis presents the development of a new method to forewarn of faults within oil impregnated current transformers. This has been based on the high frequency transients observed by the travelling wave system prior to the failure of a 330kV current transformer.

This thesis also identifies significant potential for travelling wave techniques to forewarn of developing insulator faults on overhead circuits.

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Nomenclature

a	discrete wavelet scaling constant
a_0	continuous wavelet scaling constant
a(t)	weighting function (J. Marti distributed parameter modelling)
$A(\omega)$	propagation factor
ACSR	aluminium conductor, steel reinforced
ADC	analogue to digital converter
ATP	alternative transients program
b	wavelet transformation constant
C	capacitance, F
C_T	Clarke transformation matrix
C'	capacitance per unit length, Fm^{-1}
CT	current transformer
CVT	capacitive voltage transformer
CWT	continuous wavelet transform
DFT	discrete Fourier transform
DFR	digital fault recorder
DWT	discrete wavelet transform
DDF	dielectric dissipation factor
DLA	dielectric loss angle
ε_0	permittivity of free space, 8.85×10^{-12} Fm^{-1}
ε_R	relative permittivity
e, exp	base of natural logarithms
E	magnetising voltage, V
EMTP	electromagnetic transients program
EST	eastern standard time
FFT	fast Fourier transform
f	frequency
F	magneto-motive force
F_T	Fortescue transformation matrix
G	nodal conductance matrix
GE	General Electric Co.
GPS	global positioning system

h	height, m
HV	high voltage
I	current, A
IEEE	Institute of Electrical and Electronics Engineers
Im	operator; imaginary component of a complex parameter
j	$\sqrt{-1}$
k	an integer
K_T	Karenbauer transformation matrix
l	line length, m
L	inductance, H
L'	inductance per unit length, Hm^{-1}
l_C	span length, m
ln	natural logarithm
m	fault location
n	an integer
M	mutual coupling
MCBL	minimum calculated breaking load
N	an integer, number of turns in a winding
P	per unit length potential matrix
PD	partial discharge
PVC	poly vinyl chloride
q_m	conductor charge
q	an integer
Q	charge, coulomb
r	radius, m
Re	operator; real component of a complex parameter
RCF	residual compensation factor
SCADA	system control and data acquisition
SC/GZ	steel conductor, zinc galvanised
SIR	source impedance ratio
SR	source ratio
STFT	short time Fourier transform
t, T	time, s
T	modal transformation matrix

T_C	conductor tension
ΔT	time step or relative change in time, s
T_S	sampling period, s
μ_0	permeability of free space, $4\pi x 10^{-7}$ $N.A^{-2}$ (or Wb A^{-1} m^{-1} ,Hm^{-1})
μ_R	relative permeability
V	voltage, V
v	modal velocity
V_m	conductor potential
w_C	conductor weight per meter
w	window function
$\Delta\omega$	uncertainty in angular frequency
WDFT	windowed discrete Fourier transform
x	position, displacement
$x(t)$	a signal
Δx	incremental section of line
X	reactance, Ω
X/R	ratio of source reactance to resistance
XLPE	cross-linked polyethylene
Y	shunt admittance, siemens
Z	series impedance, Ω
Z_0	surge impedance, Ω

Greek

α	$1e^{j120}$
δ	synchronising angle
ϕ	flux linkage, Tm^{-2} (or webers)
γ	propagation constant, m^{-1}
λ	matrix of eigenvalues
π	pi
ρ	Earth resistivity, Ωm
τ	time delay, s
ω	radians per second
ψ	wavelet function

Subscripts

A	phase A (red phase)
B	phase B (white phase)
C	phase C (blue phase)
AA	self interaction on the A phase
BB	self interaction on the B phase
CC	self interaction on the C phase
AB	interaction between A and B phases
BC	interaction between B and C phases
CA	interaction between C and A phases
D	discharge
E	earth
E	excitation
E_A	cable sheath on the A phase
E_B	cable sheath on the B phase
E_C	cable sheath on the C phase
f	fault
L	line
M	mutual
R	remote busbar
S	series
X	phase X on a coupled circuit
Y	phase Y on a coupled circuit
Z	phase Z on a coupled circuit
$0, 00$	zero sequence
$1, 11$	positive sequence
$2, 22$	negative sequence

Symbols which are not defined above will be specified in the text.