



**University of Technology, Sydney**

**Faculty of Engineering**

**Fault Location and Forewarning  
On Transmission Systems Using  
Travelling Wave Transients**

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**Thesis submitted in fulfilment of the requirement for the**

**Degree of Doctor of Philosophy in Engineering**

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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

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Specifically, two people were instrumental in encouraging me to search for understanding in a formal research environment. Prof. Jianguo Zhu, the principal supervisor, from the University of Technology Sydney has always been supportive and ready to provide assistance at any time. All this for a student who took time to get married in 2004, changed positions within TransGrid several times, and recently changed employers. Given this extended commitment, he has regularly found time to guide and answer my questions.

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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.



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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
$\epsilon_0$	permittivity of free space, $8.85 \times 10^{-12} Fm^{-1}$
$\epsilon_R$	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

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$h$	height, m
$HV$	high voltage
$I$	current, A
$IEEE$	Institute of Electrical and Electronics Engineers
$\text{Im}$	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, $\text{Hm}^{-1}$
$l_C$	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
$\text{Re}$	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

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$T_C$	conductor tension
$\Delta T$	time step or relative change in time, s
$T_S$	sampling period, s
$\mu_0$	permeability of free space, $4\pi \times 10^{-7} \text{ N}\cdot\text{A}^{-2}$ (or $\text{Wb A}^{-1} \text{ m}^{-1}$ , $\text{Hm}^{-1}$ )
$\mu_R$	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
$\Delta x$	incremental section of line
$X$	reactance, $\Omega$
$X/R$	ratio of source reactance to resistance
$XLPE$	cross-linked polyethylene
$Y$	shunt admittance, siemens
$Z$	series impedance, $\Omega$
$Z_0$	surge impedance, $\Omega$

**Greek**

$\alpha$	$1e^{j120}$
$\delta$	synchronising angle
$\phi$	flux linkage, $\text{Tm}^{-2}$ (or webers)
$\gamma$	propagation constant, $\text{m}^{-1}$
$\lambda$	matrix of eigenvalues
$\pi$	pi
$\rho$	Earth resistivity, $\Omega\text{m}$
$\tau$	time delay, s
$\omega$	radians per second
$\psi$	wavelet function



---

### Subscripts

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

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