
**SCHOOL OF ELECTRICAL AND ELECTRONIC
ENGINEERING**



Dynamic Phasor Estimation in Electrical Power Systems Based on IEC61850 Process-Bus

By

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Doctor of Philosophy

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Statement of Originality

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Abstract

State estimators in electrical power systems are implemented based on measurements that are provided by the SCADA systems or more recently, by dynamic phasor measurement units. The shortages of traditional SCADA systems such as the asynchronicity, the lack of using measurements with high sampling rates and complexity make them ineffective in capturing the dynamic response of a power system. Enhancing the performance of the state estimation by adding more dedicated phasor measurement units is costly. For reducing the cost and complexity of delivering measurements, IEC 61850 part-9-2 has been proposed using technology of Ethernet network communication. It uses a Process-Bus to link the equipment at switchyard and devices of protection and control at bay level. To enhance the phasor estimation and move from static to dynamic estimation, the high sampling rate of raw data provided by the Merging Unit as defined in IEC 61850 part-9-2 in combination with a Unscented Kalman filter as a dynamic estimator is proposed in the thesis. The major technical challenge that arises in applying Ethernet network communication is the impact of traffic performance on the estimated phasors and hence the substation protection and control reliability.

This thesis work is to study the performance of proposed dynamic phasor estimator influenced by delay and/or loss of the Sampled Measured Value time critical messages over the Ethernet network communication. Detailed modelling of the Sampled Measured Value packet format and the IEC 61850 based digital communication are carried out using C programming language and TrueTime simulation tool is presented. To benefit from the raw Sampled Measured Values streamed with high sampling rate from Merging Units at substation process level, Unscented Kalman Filter Model-Based for dynamic phasor estimation is developed and proposed to be used at substation bay level in this thesis. To show how some protective relays can react to the proposed dynamic phasor estimation model under the IEC 61850-9-2 communication, an overcurrent protective relay is implemented based on the proposed dynamic phasor estimation and tested against different operation conditions of the IEC 61850 Process-Bus.

I dedicate this thesis work to my Wife.

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1. A. Abdolkhalig and R. Zivanovic, "Evaluation of IEC 61850-9-2 Samples Loss on Total Vector Error of an Estimated Phasor," presented at the IEEE SCORed2013, 2013.
2. A. Abdolkhalig and R. Zivanovic, "Performance Evaluation of Phasor Estimator within IEC 61850-9-2 Communication Network," in *The International Conference on Electrical and Electronics Engineering, Clean Energy and Green Computing (EEECEGC 2013)*, Dubai, 2013, pp. 113-119.
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List of Abbreviations Used

ADC:	Analog to Digital Converter
APDU:	Application Protocol Data Unit
ASDU:	Application Service Data Unit
CSMA/CD:	Carrier Sense Multiple Access with Collision Detection
CT:	Current Transformer
DFT:	Discrete Fourier Transform
DNP:	Distributed Network Protocol
EMS:	Energy Management System
EMTDC:	Electro Magnetic Transient Direct Current Analysis
ESW:	Ethernet Switch
FIR:	Finite Impulse Response
GOOSE:	Generic Object Oriented Substation Event
GPS:	Global Positioning System
GSSE:	Generic Substation Status Event
HMI:	Human Machine Interface
IEC:	International Electro technical Commission
IED:	Intelligent Electronic Device
IEEE:	The Institute of Electrical and Electronics Engineers
IP:	Internet Protocol
IRIG-B:	Inter Range Instrumentation Group -B
KF:	Kalman Filter
LAN:	Local Area Network
MAC:	Medium Access Control
MMS:	Manufacturing Message Specification
MU:	Merging Unit
OSI:	Open Systems Interconnection
P&C:	Protection and Control
Ph-Ph:	Phase-to-Phase
PMU:	Phasor Measurement Unit
PSRC:	Power System Relaying Committee
PTP:	Precision Time Protocol
RTP:	Real Time Playback
SAS:	Substation Automation System
SIR:	Source Impedance Ratios
SMV:	Sampled Measured Values

TC: Technical Committee
TCI: Tag Control Identifier
TCP: Transmission Control Protocol
TPID: Tag Protocol Identifier
TS: Time Synchronization source
TVE: Total Vector Error
UDP: User Datagram Protocol
UKF: Unscented Kalman Filter
VLAN: Virtual Local Area Network
XML: Extensible Mark-up Language