

Green Energy and Technology

Nagwa F. Ibrahim
Sobhy S. Dessouky
Hossam E. Mostafa Attia
Ali H. Kasem Alaboudy



Protection of Wind Turbine Generators Using Microcontroller-Based Applications



Springer

Green Energy and Technology


Climate change, environmental impact and the limited natural resources urge scientific research and novel technical solutions. The monograph series Green Energy and Technology serves as a publishing platform for scientific and technological approaches to “green”—i.e. environmentally friendly and sustainable—technologies. While a focus lies on energy and power supply, it also covers "green" solutions in industrial engineering and engineering design. Green Energy and Technology addresses researchers, advanced students, technical consultants as well as decision makers in industries and politics. Hence, the level of presentation spans from instructional to highly technical.

****Indexed in Scopus**.** ****Indexed in Ei Compendex**.**

More information about this series at <https://link.springer.com/bookseries/8059>

Nagwa F. Ibrahim • Sobhy S. Dessouky
Hossam E. Mostafa Attia
Ali H. Kasem Alaboudy

Protection of Wind Turbine Generators Using Microcontroller-Based Applications

Nagwa F. Ibrahim 
Faculty of Technology and Education
Suez University
Suez, Egypt

Sobhy S. Dessouky
Faculty of Engineering
Port Said University
Port Said, Egypt

Hossam E. Mostafa Attia
Faculty of Technology and Education
Suez University
Suez, Egypt

Ali H. Kasem Alaboudy
Faculty of Technology and Education
Suez University
Suez, Egypt

ISSN 1865-3529

ISSN 1865-3537 (electronic)

Green Energy and Technology

ISBN 978-3-030-92627-4

ISBN 978-3-030-92628-1 (eBook)

<https://doi.org/10.1007/978-3-030-92628-1>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*This book dedicated to:
My mother, my sister, teachers, and friends
for their love, encouragement, and endless
support.*

*I give all thanks and gratitude to my dear
husband Mohammed Eid, and to my little
daughter Rodyna, wishing from God their
protection.*

Nagwa F. Ebrahim

Preface

We are presenting this book after study some applications on the Microcontroller Applications, specially protection of wind turbine generator. This work presents the design and implementation of a versatile digital Over Current (OC), Under Voltage (UV), Over Voltage (OV), Under Frequency (UF), Over Frequency (OF), and negative sequence relays using a single microcontroller. The software development and hardware testing are done using a microcontroller module based on an 8-bit microprocessor. Digital processing of measured currents is based on the CUSUM method in the programming. This protection provides reasonably fast tripping, even at terminal close to the power source where the most severe faults can occur, excluding the transient condition. So, this method provides an excellent balance between accuracy hardware and speed.

Motivated by economic and environmental concerns, renewable energies become of higher potential to meet the continuous increase of loads. Wind energy is one of the promising sources of renewable energy. Although the merits given by wind energy, the stochastic nature of wind is a big hinder of integrating wind power with utility grids. The wind changes over moments, hours, days, and year seasons. This book addresses the dynamic behaviour of a wind-driven induction generator (I.G.) connected to a power system grid through a transmission line. The transient responses of protective devices associated with the I.G. are also studied. A computer simulation of the system under different disturbances is conducted through the well-known matlab simulink. Disturbances considered are due to a variety of faults at the terminals of the generator as well as at the far end of the transmission line where it is connected to the load. Protective relaying strategy is proposed for the induction generator. The behaviour of different relays is studied under different disturbances.

Suez, Egypt
Port Said, Egypt
Suez, Egypt
Suez, Egypt

Nagwa F. Ibrahim
Sobhy S. Dessouky
Hossam E. Mostafa Attia
Ali H. Kasem Alaboudy

Contents

1	Introduction and Previous Work	1
1.1	Preface	1
1.2	Wind Energy Conversion System	3
1.3	Wind Energy Resources Market	3
1.4	Types of Wind Turbine Generators	4
1.5	Wind System Topologies	7
1.5.1	Constant Speed Wind Turbine Systems	8
1.5.2	Limited Variable-Speed Wind Energy Conversion System	9
1.5.3	Variable Speed Wind Turbine Systems	9
1.6	Induction Generator	11
1.6.1	Induction Generator Operation	12
1.6.2	Induction Generator Protection	12
1.6.3	Protection Requirement for Induction Generator	12
1.6.4	The Advantages Offered by Computer Relay	17
1.7	Book Objectives	17
1.8	Book Contents	18
2	Computer Simulations for the Induction Generator Connected to Power Network	19
2.1	Introduction	19
2.2	Behavior of Induction Generator	19
2.2.1	Study system	19
2.2.2	Types of Simulated Disturbances	20
2.3	Fault, Clearing, and Successful Reclosure	27
2.4	Comments and Discussion on Computer Results	30
3	Protective Schemes for Induction Generator	45
3.1	Introduction	45
3.2	Protection Requirement for Induction Generator	45
3.3	Sampling Methods	45

3.4	Conventional Fault Detection Techniques	46
3.4.1	Method 1: Sample-to-Sample Comparison Method	47
3.4.2	Method 2: Cycle-to-Cycle Comparison Method	47
3.4.3	Method 3: Cumulative Sum (CUSUM) Method	48
3.4.4	Method 4: Four Sample Method	50
3.5	Microcontroller-Based Relaying Algorithm	50
3.5.1	Frequency Deviation Algorithm.	51
3.5.2	Over-Current Algorithm.	53
3.5.3	Negative Sequence Algorithm	54
4	Transient Behavior of Induction Generator Protective Relays	59
4.1	Introduction	59
4.2	Simulation Environment	59
4.3	Types of Simulated Disturbances.	60
4.4	Types of Simulated Results	60
4.4.1	Results of Four Sample Method	60
4.4.2	Results of Sample-to-Sample Method	61
4.4.3	Results of Cycle-to-Cycle Method.	61
4.4.4	Results of Cumulative Sum Method	62
4.5	Development of Relays	62
4.6	Basic Components of Microcontroller-Based Relay	65
4.7	Proposed Delay Time Setting for Different Relays	66
4.8	Fault Response with Protection Schemes for Digital Relay	66
5	Description of Microcontroller Circuit and MikroC Program.	69
5.1	Introduction	69
5.2	Microcontroller (18F452)	69
5.2.1	Features of PIC18F452	70
5.2.2	The PIC18F452 Consists of.	72
5.2.3	Oscillator Circuit	72
5.3	LCD Display	72
5.3.1	Features	73
5.4	MAX 232.	74
5.4.1	Applications.	76
5.4.2	Features	76
5.5	Interface of DAS	76
5.6	Software Design.	77
5.7	Digital Relay MikroC Program Code	77
5.8	Different Operating Cases of Digital Relay on Proteus ISIS.	84
6	Experimental Setups and Results for Digital Relay Protection	89
6.1	Introduction	89
6.2	Experimental Setup of a SCIG-Based Wind Turbine.	89
6.2.1	Elements of the Experimental Setup	91
6.3	Main Components of the Interface Circuits Between Microcontroller and Power Circuit	93

6.3.1	Current Transformer.	93
6.3.2	Sensor Current Transformer.	95
6.3.3	Contactor	95
6.4	Hardware of Digital Relay.	95
6.4.1	Analog-to-Digital Interface Module	96
6.4.2	Central Processing Module	97
6.4.3	Operator Interface and Digital/Output Module	97
6.5	Signal Condition Circuits.	97
6.5.1	The Voltage Circuits.	97
6.5.2	The Current Circuits	98
6.5.3	The Frequency Circuit	98
6.6	Tripping Circuit	99
6.7	Testing the Relay Hardware.	100
6.7.1	Testing the Developed Software	100
6.7.2	Testing Over Current Protection Software.	100
6.7.3	Testing Over Voltage Protection Software.	100
6.7.4	Testing Under Voltage Protection Software.	100
6.7.5	Testing Over Frequency Protection Software	101
6.7.6	Testing Under Frequency Protection Software	101
6.8	Experimental Results and Discussion	101
6.9	The Effect of Digital Relay in Experimental Work	106
6.10	Summary	108
7	Conclusions and Future Work	111
7.1	Conclusions	111
7.2	Future Work	112
	Appendices.	113
	References	115
	Index.	119

About the Authors



Nagwa F. Ibrahim received her B.S. from the Faculty of Industrial Education, Suez Canal University, Suez, Egypt, in 2008; her M.Sc. from the Faculty of Industrial Education, Suez University, Suez, Egypt, in 2015; and her Ph.D. from the Faculty of Industrial Education, Suez University, Suez, Egypt, in 2019. She is currently an assistant professor in the Department of Electrical Power and Machine, Faculty of Technology and Education, Suez University. Her research interests are in the area of renewable energy sources, power system protection, power electronics, high voltage direct current (HVDC), control and power quality issues, control of power electronic converters, and electrical machine drives. Email:

Nagwa.ibrahim@ind.suezuni.edu.eg Electrical Power and Machines Department, Faculty of Technology and Education, Suez University, Suez, Egypt



Sobhy S. Dessouky was born in Dakahlie, Egypt, in 1946. He received his B.Sc. (1970) and M.Sc. (1977) degrees in electrical engineering from Suez Canal University and Helwan University, respectively. Dr. Dessouky received his Ph.D. degree from TU, Dresden, Germany, in 1982. From October 1970 to 1975, he worked in the Faculty of Engineering, Suez Canal University, as a demonstrator. Dr. Dessouky worked as a demonstrator from 1975 to 1977 in the Faculty of Engineering, Helwan University. In 1977, he worked as assistant lecturer in the Department of Electrical Engineering, Faculty of Engineering, Suez Canal

University. From 1983 to 1987, Dr. Dessouky worked as assistant professor (lecturer) in the Department of Electrical Engineering, Faculty of Engineering, Suez Canal University, Port Said Campus. In 1987, he was promoted to associate

professor in the same Department. In 1991, Dr. Dessouky became a Full Professor of Electrical Power and H.V. Engineering. He is a member of IEEE since 1996. In parallel, he worked as a department chair, vice dean for community affairs and environment, and director of the Engineering Research Center for developing technological planning at Suez Canal University. Electrical Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt



Hossam E. Mostafa Attia (M'09) was born in Cairo, Egypt, in 1965. Received his B.Sc., M.Sc., and Ph.D. from the Faculty of Engineering, Ain Shams University, Cairo, Egypt, in 1987, 1994, and 1999, respectively. From 1991 to 1997, he worked with Egyptair as a second engineer. From 1997 to 2001, worked as a teacher assistant at the College of Technological Studies, The Public Authority of Applied Education and Training (Paaet)-, Kuwait. Since 2001, he has been a faculty member with the Electrical Department at the Faculty of Industrial Education (FIE), Suez University, Suez, Egypt. He was dean of the FIE

2011–2012. Hossam worked as an associate professor in the College of Engineering, Jazan University, Saudi Arabia, in the academic year 2008–2009. He was a faculty member in the Department of Electrical and Electronic Engineering Technology at Jubail Industrial college (JIC), Saudi Arabia, from June 2013 to August 2019 and chairman from November 2013 to August 2015. Since August 2019, Hossam has been working as a professor and dean of the Faculty of Technology and Education, Suez University, Egypt. He has published more than 41 papers in international journals and conferences. Hossam has supervised more than 25 Ph.D. and M.Sc. theses, mainly in control, protection, and power quality of power systems. HE is a peer reviewer for many international journals. Hossam was involved in preparing Egypt's Smart Grid Roadmap "Egypt 2040" as a member of the Smart Grid working group, Egypt, 2010–2011. Email: hossam.attia@ind.suez.edu.eg Electrical Power and Machines Department, Faculty of Technology and Education, Suez University, Suez, Egypt



Ali H. Kasem Alaboudy (Senior Member, IEEE) received his M.Sc. and Ph.D. degrees in electrical engineering from Minia University, Egypt, in 2002 and 2009, respectively. He joined Suez Canal University as a tenure-track demonstrator and became a teaching assistant in 2002, lecturer in 2009, assistant professor in 2011, and associate professor in May 2014. Dr. Alaboudy was an RA with ECE Department, University of Waterloo, Canada, and a PDF with Masdar Institute of Science and Technology, Abu Dhabi, UAE. Currently, Dr. Alaboudy is a program manager with a national

R&D funding agency. He is expert in analyzing/addressing R&D gaps and designing thematic calls and research programs. Dr. Alaboudy was the recipient of the Suez Canal University annual awards for the excellent publication records in 2011 and 2012. His current research interests include smart grids, distributed generation, wind energy—control and power quality issues, and power system control and operation. Email: ali.alaboudy@ieee.org Electrical Power Engineering, Port Said University, Port Said, Egypt

List of Principal Symbols and Abbreviations

Symbols	Description
a, b, c, d, e, f, and g	The coefficients of the quadratic
b_{km}	The elements of this matrix
c	Filter output
g_1 and g_2	The cusum indices
i	Relay setting current
$i_1, i_2, i_3,$ and i_4	Four equally spaced samples
K	Constant of induction Machine
N	Number of samples in a period
n, B	The quadratic form matrix
R_L, L_L	Resistance and inductance of load
Re, Le	Resistance and inductance of transmission line
s	Filter 2 outputs
S(n)	Sample value at instant n
T1	Threshold parameter
Y(n)	Index value
CUSUM	Cumulative sum method
CTs	Current transformers
cx	Three-phase static capacitors bank
CB	Circuit breaker
GWEC	Global Wind Energy Council
IG	Induction generator
IP	Pickup current
I_2	The negative phase sequence current
$I_2^2 t$	The rotor heating criterion
L-G	Single line to ground fault
L-L	Line to line fault
L-L-G	Double line to ground fault
L-L-L	Three phase fault
NREA	New and Renewable Energy Authority
PVES	Photovoltaic energy system
SCIG	Squirrel cage induction generator