Modelling of an Efficient Dynamic Smart Solar Photovoltaic Power Grid System

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A Thesis Submitted in Requirement for the Degree of Doctor of Philosophy (Information Science & Engineering)

at

University of Canberra.

Faculty of Education, Science, Technology and Mathematics

September 2015.

Abstract

A smart solar photovoltaic grid system is an advent of innovation coherence of information and communications technology (ICT) with power systems control engineering via the internet [1]. This thesis designs and demonstrates a smart solar photovoltaic grid system that is self-healing, environmental and consumer friendly, but also with the ability to accommodate other renewable sources of energy generation seamlessly, creating a healthy competitive energy industry and optimising energy assets efficiency.

This thesis also presents the modelling of an efficient dynamic smart solar photovoltaic power grid system by exploring the maximum power point tracking efficiency, optimisation of the smart solar photovoltaic array through modelling and simulation to improve the quality of design for the solar photovoltaic module. In contrast, over the past decade quite promising results have been published in literature, most of which have not addressed the basis of the research questions in this thesis.

The Levenberg-Marquardt and sparse based algorithms have proven to be very effective tools in helping to improve the quality of design for solar photovoltaic modules, minimising the possible relative errors in this thesis. Guided by theoretical and analytical reviews in literature, this research has carefully chosen the MatLab/Simulink software toolbox for modelling and simulation experiments performed on the static smart solar grid system. The auto-correlation coefficient results obtained from the modelling experiments give an accuracy of 99% with negligible mean square error (MSE), root mean square error (RMSE) and standard deviation.

This thesis further explores the design and implementation of a robust real-time online solar photovoltaic monitoring system, establishing a comparative study of two solar photovoltaic tracking systems which provide remote access to the harvested energy data. This research made a landmark innovation in designing and implementing a unique approach for online remote access solar photovoltaic monitoring systems providing updated information of the energy produced by the solar photovoltaic module at the site location. In addressing the challenge of online solar photovoltaic monitoring systems, Darfon online data logger device has been systematically

integrated into the design for a comparative study of the two solar photovoltaic tracking systems examined in this thesis. The site location for the comparative study of the solar photovoltaic tracking systems is at the National Kaohsiung University of Applied Sciences, Taiwan, R.O.C.

The overall comparative energy output efficiency of the azimuthal-altitude dual-axis over the 45^0 stationary solar photovoltaic monitoring system as observed at the research location site is about 72% based on the total energy produced, estimated money saved and the amount of CO_2 reduction achieved. Similarly, in comparing the total amount of energy produced by the two solar photovoltaic tracking systems, the overall daily generated energy for the month of July shows the effectiveness of the azimuthal-altitude tracking systems over the 45^0 stationary solar photovoltaic system. It was found that the azimuthal-altitude dual-axis tracking systems were about 68.43% efficient compared to the 45^0 stationary solar photovoltaic systems. Lastly, the overall comparative hourly energy efficiency of the azimuthal-altitude dual-axis over the 45^0 stationary solar photovoltaic energy system was found to be 74.2% efficient.

Results from this research are quite promising and significant in satisfying the purpose of the research objectives and questions posed in the thesis. The new algorithms introduced in this research and the statistical measures applied to the modelling and simulation of a smart static solar photovoltaic grid system performance outperformed other previous works in reviewed literature. Based on this new implementation design of the online data logging systems for solar photovoltaic monitoring, it is possible for the first time to have online on-site information of the energy produced remotely, fault identification and rectification, maintenance and recovery time deployed as fast as possible.

The results presented in this research as Internet of things (IoT) on smart solar grid systems are likely to offer real-life experiences especially both to the existing body of knowledge and the future solar photovoltaic energy industry irrespective of the study site location for the comparative solar photovoltaic tracking systems. While the thesis has contributed to the smart solar photovoltaic grid system, it has also highlighted areas of further research and the need to investigate more on improving the choice and quality design for solar photovoltaic modules. Finally, it has also made recommendations for further research in the minimization of the absolute or relative errors in the quality and design of the smart static solar photovoltaic module.

Acknowledgements

This dissertation would have never been written, much less completed without acknowledging the unmerited mercies, love and favour of the Almighty God for His unfailing grace, strength, knowledge and wisdom throughout the learning process of my doctoral studies.

I would like to express sincere gratitude to my primary supervisor, Prof. Xu Huang, for his excellent guidance and counsel, patience, providing insightful comments, valuable contribution and support over the course of my research. I would also like to thank my co-supervisor A/Prof. Dat Tran for his encouragement and moral support in every step of this research work. I wish to express my indebtedness to fellow research colleagues, and all administrative staffs at the National Kaohsiung University of Applied Sciences, Taiwan, the Republic of China for their guidance, cooperation and support during my research visit for data collection.

My sincere thanks also go to Mrs Carmela Thambirajah Adisa and family for their timely and invaluable support at the hour of distress during my study. I would also like to express sincere gratitude to Dr Abayomi Adeniyi and family for their moral guidance and support. I would like to thank every member and friends of the Ammish family, especially Dr Ammish Adu and Dr Joyce Adu for their unflinching and unfailing assistance and encouragement to persevere in finishing my doctoral research.

I would like to thank Dr Michael S. Adelana and all members of the Deeper Christian Life Ministry, Australia for their timely and financial support in the period of crisis and ceaseless prayers supporting me spiritually throughout this study period. I would like to thank my fellow research mates for their thought-provoking discussions across all works of life, for the opportunities to work together, and for all the fun in sports, we had in the last three years.

I am indebted to the Lagos State Government Scholarship Board, Nigeria for granting me the opportunity to undertake this research study at the University of Canberra, Australia for their financial commitment was invaluable to me in completing my doctoral studies. Special thanks to all who have crossed my paths during this journey, who has in one way or another been a blessing contributing to the successful completion of this dissertation.

Last but not the least, I would like to thank my parents, especially my mother for her ceaseless prayers and mobile calls since I left for this doctoral studies and my beloved wonderful sisters for their concern on my study progress and unconditional support in taking good care of my dad.

List of Acronyms

AADAT	Azimuth-Altitude Dual Axis Tracker
ANN	Artificial Neural Network
CCD	Charge Coupled Device
Cfcs	Chlorofluorocarbons
CO_2-e	Carbondioxide Equivalent
CPV	Concentrated Photovoltaic
CR	Time Constant
CSP	Concentrated Solar Power
CVR	Conservation Voltage Reduction
DLS	Damped Least-Squares
EPA	Environment Protection Agency
EPRI	Electric Power Research Institute
FDIR	Fault Detection, Isolation And Restoration
GDP	Gross Domestic Product
GHG	Green House Gases
GM-Estimators	Generalized M-Estimators
GNA	Gaussian-Newton Algorithm
GPS	Global Positioning System
GUI	Graphical User Interface
HSAT	Horizontal Single Axis Tracker
IAAS	Infrastructure As A Service
ICT	Information and Communication Technology
IP	Internet Protocol
IREAs	International Renewable Agencies
ISA	International Society Of Automation
ISP	Internet Service Providers
IVVCO	Integrated Volt-Var Control Optimisation

IoT	Internet of Things
LAD	Least Absolute Deviation
LDRs	Light Dependent Resistors (Or Photo-Resistors),
LMA	Levenberg-Marquadt Algorithm
LREs	Large Renewable Energy Schemes
LT	Local Times
LTS	Least Trimmed Squares
MLP	Multilayer Perceptron
MPPT	Maximum Power Point Tracking
MSE	Mean Square Error
NERC CIP	North American Electric Reliability Corporation Critical Infrastructure Protection
NIPP	National Infrastructure Protection Plan
NIST	National Institute Of Standard And Technology
NREAP	National Renewable Energy Action Plan
O&M	Operations And Maintenance
OLS	Ordinary Least Squares
PAAS	Platform As A Service
PASAT	Polar Aligned Single Axis Tracker
PC	Personal Computers
P-I-N Diode	Photo-Diode
PLC	Programmable Logic Control
PSpice	Personal Computer Simulation Program with Integrated Circuit Emphasis
PV	Photo-Voltaic
QoS	Quality of Service
RBF	Radial Basis Function
REAs	Renewable Energy Agencies
RECs	Renewable Energy Credits
RES	Renewable Energy Sources

RETs	Renewable Energy Targets
RMSE	Root Mean Square Error
RPS	Renewable Portfolio Standards
SAAS	Software As A Service
SGN	Smart Grid Network
SRES	Small Renewable Energy Schemes
T&D	Transmission And Distribution
TSAT	Tilted Single Axis Tracker
TTDAT	Tip-Tilt Dual Axis Tracker
UCAAS	Unified Communication As A Service
UV	UltraVoilet
VSAT	Vertical Single Axis Tracker.
WCRE	World Council For Renewable Energy

List of Symbols

I_{ph}	*photo current generator*
I_o	*leakage or reverse saturation current*
q	*electron charge*
V	*solar cell voltage*
A	*ideality factor*
k	*Boltzmann constant*
R_S	*series cell resistance*
R_{sh}	*shunt cell resistance*
T_a	ambient temperature
w_s	*wind speed*
S	solar *irradiation*
I_{or}	I_o at reference temperature at T_r = 301.18K
E_G	band gap energy
T_r	reference temperature
T	solar cell temperature
I_{scr}	short circuit current at T_r
k_i	short circuit current temperature coefficient
V_{OC}	open circuit voltage
V_{mp}	maximum power voltage
I_{mp}	maximum power current
n_p	number of parallel modules
n_s	number of series modules
P	output power

List of Publications

- **Balogun, Emmanuel B.**, Xu Huang, and Dat Tran. "Efficiency of Sensor Devices Used in Dynamic Solar Tracking System: Comparative Assessment Parameters Review." *Applied Mechanics and Materials* 448 (2014): 1437-1445.
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- **Balogun, Emmanuel B.**, Xu Huang, and Dat Tran. "Comparative Study of Different Artificial Neural Networks Methodologies on Static Solar Photovoltaic Module." "International Journal of Emerging Technology and Advanced Engineering" Volume 4, Issue 10, October 2014(ISSN 2250-2459(Online)): 674-685.
- **Balogun, Emmanuel B.**, Xu Huang, Dat Tran, Yun-Chuan Lin, Mingyu Liao, and Michael Adaramola. "Regression estimation modelling techniques on static solar photovoltaic module" "International Journal of Emerging Technology and Advanced Engineering" Volume 5, Issue 4, April 2015 (ISSN 2250-2459(Online)): 451-461.
- **Balogun, Emmanuel B.**, Xu Huang, Dat Tran, Yun-Chuan Lin, Mingyu Liao, and Michael Adaramola. "A robust real-time online comparative monitoring of an azimuthal-altitude dual axis GST 300 and a 45° fixed solar photovoltaic energy tracking systems." In *SoutheastCon 2015*, pp. 1-10. IEEE, 2015.
- **Balogun, Emmanuel B.**, Xu Huang, Dat Tran, Yun-Chuan Lin, Mingyu Liao, and Michael Adaramola. "Power quality improvement by integration of Distributed Networks" "International Journal of Emerging Technology and Advanced Engineering" Volume 5, Issue 7, July 2015 (ISSN 2250-2459(Online)): 465-471.

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