Faculty of Electrical Technology and Engineering

INTELLIGENT ALGORITHM BASED MODELING OF RENEWABLE AND GREEN ENERGY RESOURCES FOR MICROGRID OPTIMIZATION

Alias Bin Khamis

Doctor of Philosophy

2025

INTELLIGENT ALGORITHM BASED MODELING OF RENEWABLE AND GREEN ENERGY RESOURCES FOR MICROGRID OPTIMIZATION

ALIAS BIN KHAMIS

A thesis submitted
in fulfilment of the requirements for the degree of
Doctor of Philosophy

Faculty of Electrical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2025

DECLARATION

I declare that this thesis entitled "Intelligent Algorithm Based Modeling of Renewable and Green Energy Resources for Microgrid Optimization" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	………………………………………………
Name	:	ALIAS BIN KHAMIS
Date	:	6 MAY 2025
		………………………………………………

APPROVAL

I hereby declare that I have read this thesis and, in my opinion, this thesis is sufficient in terms of scope and quality for the award of Doctor Philosophy.

Signature	:	
Supervisor Name	:	PROFESSOR IR. DR. GAN CHIN KIM
Date	:	7 MAY 2025

………………………………………………

DEDICATION

To my loving family, supportive friends and supervisor who have been my pillars of strength and inspiration throughout this project

ABSTRACT

The reduction of fossil fuels, rising oil prices and environmental awareness have attracted attention to the use of renewable energy (RE) based distributed generator (DG) systems. Among the various types of renewable energy-based DG, Photovoltaic (PV) and Fuel Cell (FC) technology has shown great potential in electricity generation due to rapid technological development, high efficiency, clean operation and slightly influenced by weather conditions. To ensure optimal DG output, the RE system must be coordinated using a voltage controller and optimization techniques to determine the optimal DG output voltage and power value. To improve the AC bus arrangement, Battery power is connected to a down/up converter to ensure continuous power flow between the Alternating Current (AC) bus and the Battery. In order to control the voltage source inverter (VSI) of the PV/Fuel Cell/Battery cell system, conventional methods of control-voltage modes and currents with improved controllers of the Artificial Intelligent (AI) of both the internal current control loop and the output voltage were built. The proposed tuned Artificial Neural Network (ANN) controller has an advantage over the Adaptive Neuro-Fuzzy Inference System (ANFIS) controller while maintaining the simplicity and robustness of the Proportional Integral (PI) controller. The inverter-based DG model is applied to the micro-grid-system to review its effectiveness as a complete model as well as to evaluate the performance of its use in large network systems. Since the VSI model is built on a P-Q control scheme that allows separate control of active and reactive power output, DG can operate based on active and reactive power reference on the inverter. A new smart technique has been developed to manage active and reactive power reference for DG by using ANN to ensure that the DG unit operates at optimal power values while reducing the amount of power loss as well as maintaining the voltage profile within acceptable limits. The results showed that the proposed tuned ANN technique could accurately predict the active and reactive power references of DG with minimal error. A comparison was made between the ANN DG controller and the ANFIS DG controller for the power management strategy in terms of the generation by standard forecasting metrics. The comparison between the proposed AI controller and the conventional PI controller has been conducted and the results showed that the proposed tuned artificial NN technique could accurately predict the active and reactive power references of DG with minimal error. For active power of Battery, is 0.23%, Fuel Cell is 0.23%, reactive power of Battery is 0.0175%, Fuel Cell is 0.097%, Photovoltaic PV1, 0.078% and PV2 is 0.021%. At the end of the research AI controller was evaluation/validation of the effectiveness by comparative also conducted to assess the performance and forecast accuracy of the tuned AI that has been chosen by forecasting metrics, which show the good estimation performance in only 1.6E-14 % for coefficient of determination (R^2), 5.86E-05% for root mean square error (RMSE), 9.1E-06% mean absolute error (MAE) and 0.011% for mean absolute percentage error (MAPE).

PEMODELAN BERASASKAN ALGORITMA PINTAR SUMBER TENAGA BOLEH DIPERBAHARUI DAN HIJAU UNTUK PERNGOPTIMANKANMICROGRID

ABSTRAK

Pengurangan bahan api fosil, kenaikan harga minyak dan kesedaran alam sekitar telah menarik perhatian kepada penggunaan sistem penjana teragih (PT) berasaskan tenaga boleh diperbaharui (TB). Antara pelbagai jenis teknologi (PT) berasaskan tenaga boleh diperbaharui, Photovoltaic (PV) dan sel fuel (SF) telah menunjukkan potensi besar dalam penjanaan elektrik berikutan pembangunan teknologi yang pesat, kecekapan tinggi, operasi yang bersih dan sedikit dipengaruhi oleh keadaan cuaca. Untuk memastikan output PT optimum, sistem TB mesti diselaraskan menggunakan pengawal voltan dan teknik pengoptimuman untuk menentukan keluaran optimum voltan dan nilai kuasa PT.Untuk menambah baik susunan bas AU, kuasa Bateri disambungkan kepada penukar bawah/atas untuk memastikan aliran kuasa berterusan antara bas Arus Ulang-alik (AU) dan Bateri. Untuk mengawal Penyongsang Punca Voltan (PPV)bagi PV/sel Bahan Api/sel sistem Bateri, kaedah konvensional mod voltan kawalan dan arus dengan pengawal yang dipertingkatkan bagi Kecerdasan Buatan (KB) bagi kedua-dua gelung kawalan arus dalaman dan voltan keluaran telah dibina. Pengawal Rangkaian Neural Buatan (RNB) yang dicadangkan mempunyai kelebihan berbanding pengawal Sistem Inferens Neuro-Fuzzy Adaptif (ANFIS) sambil mengekalkan kesederhanaan dan keteguhan pengawal Kadar Pengamiran (KP). Model PT berasaskan penyongsang digunakan pada sistem-grid mikro untuk menyemak keberkesanannya sebagai model lengkap serta menilai prestasi penggunaannya dalam sistem rangkaian besar. Memandangkan model PPV dibina di atas skim kawalan P-Q yang membenarkan kawalan berasingan bagi keluaran kuasa aktif dan reaktif, PT boleh beroperasi berdasarkan rujukan kuasa aktif dan reaktif pada penyongsang. Teknik pintar baharu telah dibangunkan untuk mengurus rujukan kuasa aktif dan reaktif untuk PT dengan menggunakan RNB untuk memastikan unit PT beroperasi pada nilai kuasa optimum sambil mengurangkan jumlah kehilangan kuasa serta mengekalkan profil voltan dalam had yang boleh diterima. Keputusan menunjukkan bahawa teknik RNB buatan yang dicadangkan boleh meramal dengan tepat rujukan kuasa aktif dan reaktif PT dengan ralat yang minimum. Perbandingan telah dibuat antara pengawal PT RNB dan pengawal PT ANFIS untuk strategi pengurusan kuasa dari segi penjanaan mengikut metrik ramalan standard. Perbandingan antara pengawal KB yang dicadangkan dan pengawal KP konvensional telah dijalankan dan keputusan menunjukkan bahawa teknik RBN buatan yang dicadangkan boleh meramal dengan tepat rujukan kuasa aktif dan reaktif PT dengan ralat yang minimum. Untuk kuasa aktif Bateri ialah 0.23%, sel Bahan Api ialah 0.23%, kuasa reaktif Bateri ialah 0.0175%, sel Bahan Api ialah 0.097%, Photovoltaic PV1, 0.078% dan PV2 ialah 0.021%. Pada akhir kajian, pengawal KB adalah penilaian/pengesahan keberkesanan secara perbandingan juga dijalankan untuk menilai prestasi dan ketepatan ramalan bagi kecerdasan buatan yang telah dipilih oleh metrik ramalan, yang menunjukkan prestasi anggaran yang baik dalam hanya 1.6E- 14 % untuk pekali penentuan (R^2), 5.86E-05% untuk punca ralat min kuasa dua (RMSE), 9.1E-06% min ralat mutlak (MAE) dan 0.011% untuk ralat peratusan mutlak (MAPE).

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to Allah, the Almighty, for blessing me with the strength, guidance, and perseverance to complete this project. His unwavering support has been instrumental in my journey. I extend my sincere appreciation to my supervisor, Prof. Ir. Dr. Gan Chin Kim, my co-supervisor Assoc. Prof. Dr. Mohd Shahrieel bin Mohd Aras for his invaluable guidance, sharing of knowledge, and unwavering support throughout this project. His expertise and encouragement have played a crucial role in shaping the outcome of this research. I am grateful to Universiti Teknikal Malaysia Melaka for providing the platform and resources necessary for the successful completion of this project. The academic environment and opportunities offered by the university have greatly contributed to my personal and professional growth. I would also like to thank the Faculty of Electrical Technology and Engineering for their continuous support and the wealth of knowledge imparted during my academic journey. Their dedication to excellence has been an inspiration. Finally, I extend my deepest appreciation to my family and friends for their unwavering love, encouragement, and understanding throughout this project. Their presence and belief in me have provided the motivation and strength needed to overcome challenges and achieve my goals. Their unwavering support has been invaluable, and I am forever grateful for their presence in my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternating current
ANN	-	Artificial neural network
BIPV	-	Building integrated photovoltaic
BES	-	Battery energy storage
BESS	-	Battery energy storage system
CHP	-	Combine heat and power
DC	-	Direct current
DG	-	Distributed generation
DER	-	Distributed energy resource
FC	-	Fuel cell
FCGS	-	Fuel cell generation system
GE	-	Green energy
IGBT	-	Insulated Gate Bipolar Transistor
kW	-	Kilowatt
Li-Ion	-	Lithium Ion
MBIPV	-	Malaysia Building Integrated Photovoltaic
MCFC	-	Molten Carbonate Fuel Cell
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
MPPT	-	Maximum power point tracking
NiCd	-	Nickel Cadmium
NiMH	-	Nickel Metal Hydride
PAFC	-	Phosphoric Acid Fuel Cell
PCS	-	Power conditioning system
PED	-	Power electronics device
PEM	-	Proton Exchange Membrane
PMSM	-	Permanent magnet synchronized machine
PVGS	-	Photovoltaic generation system
PV	-	Photovoltaic
RE	-	Renewable energy
REDG	-	Renewable energy based distributed generation
RES	-	Renewable energy source

RMS	-	Root mean square
SG	-	Synchronous generator
SOC	-	State of charge
SOFC	-	Solid Oxide Fuel Cell
THD	-	Total harmonic distortion
TNB	-	Tenaga Nasional Berhad
VSI	-	Voltage source inverter

LIST OF SYMBOLS

I_{pv}	-	the photovoltaic current of the array
I_o	-	the photovoltaic current of the array
V_t	-	the thermal voltage of the array
N_s	-	total number of photovoltaic in series
N_p	-	total number of photovoltaic in parallel
R_s	-	equivalent series resistance
R_p	-	equivalent parallel resistance
a	-	may be arbitrarily chosen
$I_{pv,n}$	-	light generated current at 25 ° C and 1000W/m^2
ΔT	-	differences of actual and nominal temperatures
K_I	-	current coefficient
G	-	irradiation on the device surface
G_n	-	nominal irradiation
$V_{t,n}$	-	thermal voltage at nominal temperature
$V_{oc,c}$	-	open-circuit voltage at nominal temperature
$I_{sc,n}$	-	short-circuit current at nominal temperature
H_2	-	hydrogen
O_2	-	oxygen
H_{2O}	-	water
N_0	-	the number of series Fuel Cell in the stack
U_{NL}	-	the standard no load voltage
k_{UGC}	-	the universal gas constant
R_{int}	-	the absolute temperature
I_{FC}	-	internal resistance of Fuel Cell

I_{FC}	-	the Fuel Cell stack current
η_{act}	-	a function of the oxygen concentration and stack current
η_{ohmic}	-	a function of the stack current and the stack internal resistance
E	-	no-load voltage
E_o	-	Battery constant voltage
K	-	polarization voltage
Q	-	Battery capacity
A	-	exponential voltage
B	-	exponential capacity
i	-	Battery current
P_{GEN}	-	active power from RE/GE source
P_{CON}	-	active power of converter,
c_{DC}	-	the capacitance inside a DC-link
u_{DC}	-	the DC-link voltage
P_a, P_c	-	the overall gas pressure at the electrode anode (a) and cathode (c)
l_a, l_c	-	the distances from electrode surface for anode and cathode
N_{cell}	-	the number of cells in the stack
U_{delay}	-	the voltage drops due to effect of fuel and oxidant delay
λ_e	-	a constant
τ_e	-	the overall flow delay
P_{FCGS}	-	active power of Fuel Cell generation system
P_{BESS}	-	active power of Battery energy storage system
Q_{PVGS}	-	reactive power of PV generation system
Q_{FCGS}	-	reactive power of Fuel Cell generation system
Q_{BESS}	-	reactive power of Battery energy storage system

LIST OF APPENDICES