Dedicated to my parents who have

been my first teachers and my biggest support

throughout my learning life.

Declaration

I, **Barnam Jyoti Saharia**, hereby declare that the present thesis, entitled **Development of soft computing modality for optimization of Renewable Energy Systems**, is the record of work done by me under the supervision of **Dr. Nabin Sarmah, Assistant Professor, Department of Energy**. The contents of the thesis represent my original work that have not been previously submitted for any Degree/Diploma/Certificate in any other University or Institution of Higher Education.

I certify that

- I have followed the guidelines provided by Tezpur University in writing the thesis.
- I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the university.
- Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the dissertation and giving their details in the references.

This thesis is being submitted to **Tezpur University** for the Degree of Doctor of Philosophy in **Energy**.

Bj Saharia

Place: Tezpur University

Date: 28/06/2024

(Barnam Jyoti Saharia)

Department of Energy
Tezpur University
Napaam, Tezpur- 784028, Assam, India.

Dr. Nabin Sarmah
Assistant Professor

Phone:+91-3712-275314
Fax:+91 3712 267005
E-Mail : nabin@tezu.ernet.in

Certificate

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All helps received by him from various sources have been duly acknowledged. No part of this thesis has been submitted else where for award of any other degree.

Nabin 28/6/2024.

(*Supervisor*)

Dr. Nabin Sarmah
Assistant Professor, Department of Energy
School of Engineering, Tezpur University
Assam, India-784028

June, 2024

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The Committee recommends for award of the degree of Doctor of Philosophy.

27/3/2025

Signature of Principal Supervisor

Signature of External Examiner

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Date: (Barnam Jyoti Saharia)

Department of Energy
Tezpur University
Napaam, Tezpur- 784028, Assam, India.

Dr. Nabin Sarmah
Assistant Professor

Phone:+91-3712-275314
Fax:+91 3712 267005
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Barnam Jyoti Saharia

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List of Algorithms

List of Acronyms

ABC	Artificial Bee Colony
AC	Alternating Current
ACO	Ant Colony Optimization
AEFA	Artificial Electric Field Algorithm
AHA	Artificial Humming Bird Algorithm
AIS	Artificial Immune System
ALO	Ant Lion Optimization
AMFA	Adaptive Modified Firefly Algorithm
ANN	Artificial Neural Networks
ANFIS	Adaptive Neuro Fuzzy Inference System
ANOVA	One way Analysis of Variance
AOA	Arithmetic Optimization Algorithm
ASO	Atom Search Optimization
AT&C	Aggregate Technical and Commercial
BA	Bat Algorithm
BB-BC	Big Bang Big Crunch
BW	Bandwidth
CCM	Continuous Conduction Mode
CO_2	Carbon Dioxide
COE	Cost of Energy
CS	Cuckoo Search
CVM	Continuous Voltage Mode
DC	Direct Current
DC-DC	Direct Current to Direct Current
DCM	Discontinuous Conduction Mode
DE	Differential Evolution
DFA	Dragon Fly Algorithm
DLH	Dimension Learning Based Hunting
DSM	Demand Side Management
EMI	Electromagnetic Interference

EO	Equilibrium Optimizer
FFA	Firefly Algorithm
FDA	Flow Direction Algorithm
FSC	Fractional Short Circuit
FLA	Fuzzy Logic Algorithm
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
GWO	Grey Wolf Optimizer
GWOSCAPSO	Grey Wolf Optimizer Sine Cosine Algorithm Particle Swarm Optimization
HBB-BCA	Hybrid Big Bang-Big Crunch Algorithm
HBMA	Honey Bee Mating Algorithm
HHO	Harris Hawk's Optimization
HRES	Hybrid Renewable Energy Systems
IC	Incremental Conductance
ICA	Imperialist Completion Algorithm
IGWO	Improved Grey Wolf Optimizer
IMD	Indian Meteorological Department
I-V	Current vs Voltage
LCOE	Levelized Cost of Energy
LV	Low Voltage
MATLAB	Matrix Laboratory
MBA	Mine Blast Algorithm
MFO	Moth Flame Optimization
MNRE	Ministry of New and Renewable Energy
MPA	Marine Predator Algorithm
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MPSO	Modified Particle Swarm Optimization
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MVO	Multi Verse Optimizer
MW	Mega Watts
NEEPCO	North Eastern Electric Power Corporation
NHPC	National Hydroelectric Power Corporation
NREL	National Renewable Energy Laboratory
NSGA	Nondominated Sorting Genetic Algorithm
NTPC	National Thermal Power Corporation
O&M	Operation and Maintenance

ONCG	Oil and Natural Gas Commission
OTPC	ONGC Tripura Power Company Limited
P&O	Perturb and Observe
PPU	Power Processing Units
PSO	Particle Swarm Optimization
PV	Photovoltaic
PWM	Pulse Width Modulation
QOHSA	Quasi-Oppositional Harmony Search Algorithm
RPG	Relative Power Gain
RPL	Relative Power Loss
SA	Simulated Annealing
SCA	Sine Cosine Algorithm
SEFC	Single Ended Forward Converter
SHPS	Small Hydro Power Plant System
SPVS	Solar Photovoltaic System
SSA	Scalp Swarm Algorithm
TLBO	Teaching Learning Based Optimization
WCA	Water Cycle Algorithm
WOA	Whale Optimization Algorithm

List of Symbols

α	A scaling factor which is responsible for controlling the step sizes in a random fashion in Firefly Algorithm
β_o	Is the constant that determines the attractiveness between fireflies when the distance between them is zero.
θ	Parameter responsible for reduction of the randomness within the values of (0,1] in Firefly Algorithm
Δi_1	Change in inductor current
Δv_o	Change in output voltage
η	Efficiency
η_{tb}	Conversion efficiency of turbine
ω_o	Bandwidth
Ω	Ohm
γ	Parameter regulating the discernibility of the fireflies
η_B	Efficiency of Battery,
$\eta_{PV,m}$	Conversion efficiency of the solar module.
ρ	Density of water, g/m^3
$\overrightarrow{a}$	Parameter of the algorithm which reduces from 2 to zero over iterations
$\overrightarrow{A}$, $\overrightarrow{C}$	Co-efficient Vectors
A	Surface area of the PV system, m^2,
A_{CC}	Annual capital cost , Rs
$A_{O\&M}$	Annual operation and maintenance cost , Rs.
A_{PV}	Area of the PV system, m^2
$A_{PV.max}$	Maximum Area of the PV system, m^2
A_{Sal}	Annual salvage value of HRES, Rs

ALC	Annual levelized cost, Rs
C	Value of Capacitance/ Capacitor
$\overrightarrow{C_1}, \overrightarrow{C_2}, \overrightarrow{C_3}$	Co-efficient vectors related to position of alpha, beta and delta wolf respectively
$C_{A,h}$	Capacity of Battery, Ah
$C_{A,h1}$	Capacity of single Battery, Ah.
$C_{BAT,C}$	Capital cost of batteries ,Rs.
C_{CW}	Cost of Civil Works, Rs
C_{EW}	Cost of Electromechanical Equipment, (INR/kW)
C_H	Capacity of the hydro system, W
$C_{H,C}$	Capital cost of hydro system Rs.
C_{min}, C_{1min}, C_{2min},	Minimum Value of Capacitor
C_{max},C_{1max}, C_{2max}	Maximum Value of Capacitor
$C_{PV,C}$	Capital cost of PV , Rs.
$C_{PV,e}, C_{H,e}, C_{BAT,e}$	Erection cost of PV and hydro system, and batteries respectively Rs.
$C_{PV,m}, C_{H,m}$	Mechanical cost of PV and hydro system, Rs.
$C_{PV,O\&M}, C_{H,O\&M}, C_{BAT,O\&M}$	Operation and maintenance cost of PV and hydro system, and batteries respectively, Rs.
$C_{PV,Sal}, C_{H,Sal}$	Salvage value of PV and hydro system, Rs.
CRF	Capital recovery factor
D	Duty Ratio
$\frac{di_1}{dt}$	Rate of Change of Inductor Current
$\frac{dv_o}{dt}$	Rate of Change of output voltage
D_A	Days of Autonomy
D_i	The absolute value of the distance between the particle (or search agent) in moth flame algorithm
D_{max}	Maximum demand, W
DoD	Depth of Discharge
$E_{g,HRES}$	Guaranteed energy output per year, Wh
E_H	Energy generated from the turbine, Wh
$E_L(t)$	Energy supplied, kWh
E_L	Daily energy consumption, Wh
E_{PV}	Energy output from the PV system, Wh
f_s	Switching Frequency

f_{smin}	Minimum Value of switching frequency
f_{smax}	Maximum Value of switching frequency
F_j	Local solution in Moth Flame Algorithm
g	Gravitational acceleration, m/sec^2
g_{besti}	The global best value of the swarm
I	Current
G_T	Incident global radiation, W/m^2,
H	Gross head of the turbine, m
H_2	Hydrogen
H_{max}	Maximum head of the turbine, m
i_{inf}	Inflation rate.
i_1	Inductor Current
i_{nom}	Nominal interest rate
I_{MPP}	Current at Maximum Power Point
I_{ph}	Photo Current
I_{SC}	Short Circuit Current
k	Boltzmann's Constant / Coupling factor
L	Value of Inductance/Inductor
L_{max} , L_{1max}, L_{2max}	Maximum Value of Inductor
L_{min}, L_{1min}, L_{2min}	Minimum Value of Inductor
m	A factor which depends on capacity of hydro system and number of units in hydro system, m < 1 .
N_{BAT}	Number of battery required,
P_{besti}	Best particle value
P_{cond}	Power Loss in the capacitor
$P(R_{e,PV})$	Probability of radiation to be exceeded,
$P(R_{e,H})$	Probability of runoff to be exceeded,
P_{ind}	Power loss in the inductor
P_{BOOST}	Power loss in the boost converter
P_H	Capacity of Hydro system, kW
$P_{H,h}$	Hydraulic power at the turbine shaft, W
$P_{H,m}$	Mechanical power output, W
P_{LOAD}	Output Power
$P_{mpp,i}$	MPP tracked by either ANN or FLA
$P_{mpp,P\&O}$	The MPP tracked by the P&O algorithm.
P_{PV}	Capacity of PV system, kW
P_{PV}	Output power from the PV system, W

$P_{PV,e}$	Electrical power output from the PV system, W,
$P_{PV,peak}$	Power output from PV system at peak radiation, W
P_{ON}	On state power loss
P_{Q1}	Power loss in the switch $Q1$
P_{SW}	Power Loss due to switching
P_{TH}	Theoretical maximum power produced by the PV panel at a given condition of Radiation and Temperature
$Q_{rr}^{Schotty}$	Diode Body Charge as per Schotty equation
$Q(t)$	Water discharge through turbine, m^3/sec
$Q(t)_{min}$	Minimum discharge of turbine
$Q(t)_{max}$	Maximum discharge of turbine
r_1, r_2	Random numbers between [0,1]
r_{ij}	Gives the distance between i^{th} and j^{th} fireflies in terms of the Cartesian co-ordinates
R	Resistance/ Resistor
R_C	Series Resistance of Capacitor
R_{depth}	Direct runoff depth of the drainage, mm
R_D	Radiation used for sizing of PV system, W/m^2
$R_{D.max}$	Radiation used for sizing of PV system, W/m^2
R_{DS}	On state resistance of MOSFET
R_L	Load Resistance/ Inductors Loss Component of Resistance
R_{LI}	Reflected Load Impedance
R_{IN}	Input Resistance to the converter
R_{MPP}	Resistance at Maximum Power Point
R_s	Series Resistance
R_{SH}	Shunt Resistance
s_i	Particle Trajectory in Moth Flame Algorithm
t_a	Outside air temperature, $^{\circ}C$,
T	Cell Temperature $^{\circ}C$,
T_C	Concentration time, minute, in

$T_{g,H}$	Guaranteed time for which runoff to be exceeded, h
$T_{g,PV}$	Guaranteed time for which radiation to be exceeded, h
$T_{h,PV}$	Total sunshine duration over year, h .
T_s	Switching Period
T_{swon}	On time of converter
T_{swoff}	Off time of converter
T_{Sun}	Time period for which sunlight is falling on PV system, h.
$T_{Turbine}$	Time period for which turbine is active, h.
u	State of Switch
V_f	On state voltage drop in semiconductor
V$_{DC}$	DC Voltage
v_{in}/v_g	Input Voltage
v_i^{k+1}	Velocity of the swarms i^{th} particle for the (k+1)th iteration
V_{in}	Input Voltage
v_o	Output Voltage
w	Initial weight Factor
x_i	Position of the i^{th} particle
x_i^{k+1}	Position of the i^{th} particle of the swarm for the (k+1)th iteration
$\overrightarrow{X}$	Vectors containing the position of the grey wolf
$\overrightarrow{X_P}$	Vectors containing the position of the prey
$\overrightarrow{X_\alpha}$	Position vector for alpha grey wolf
$\overrightarrow{X_\beta}$	Position vector for beta grey wolf
$\overrightarrow{X_\delta}$	Position vector for delta grey wolf