Om Namah Shivaay

DEDICATION

For *Maa*, the brightest star in my sky.

For *Papa*, because of whom I am me today.

For my *Pranvie*, who has come as my life's greatest blessing.

"Trifles make perfection, and perfection is no trifle" – Michael Angelo

DECLARATION BY THE CANDIDATE

I do hereby declare that the thesis titled "**Road Load Model Based Energy and Range Estimation for Eco-routing Navigation of Electric Vehicles**", submitted to the Department of Electronics and Communication Engineering, Tezpur University, Tezpur, Assam, is a record of original research work carried out by me. All sources of assistance for my Ph.D. work have been duly acknowledged. I also declare that neither this work as a whole nor a part of it has been submitted to any other University or Institute for the award of any degree or diploma.

Kritanjali Das

(Kritanjali Das)

Regn. No. TZ203795
Enrol. No. ELP16005

Date: 30·8·2023
Place: Tezpur

TEZPUR UNIVERSITY

Department of Electronics and Communication Engineering
Napaam, Tezpur, Assam, India-784028

Dr. Santanu Sharma
Professor

Ph.:+91-3712-275257
Fax:+91-3712-267006
Email : sss@tezu.ernet.in

CERTIFICATE OF THE SUPERVISOR

This is to certify that the thesis titled "**Road Load Model Based Energy and Range Estimation for Eco-routing Navigation of Electric Vehicles**", submitted to the School of Engineering, Tezpur University in part fulfillment for the award of degree of Doctor of Philosophy in Electronics and Communication Engineering is a research work carried out by **Ms.Kritanjali Das** under my supervision and guidance.

All help received by her from various sources have been duly acknowledged.

No part of this thesis has been submitted elsewhere for the award of any other degree or diploma to the best of my knowledge.

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Signature of supervisor

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"No duty is more urgent than that of returning thanks."- James Allen

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(Kritanjali Das)
Place: Tezpur, Assam

Figures

Tables

Abbreviations

AEV	All Electric Vehicle
BEV	Battery Electric Vehicle
BJT	Bipolar Junction Transistor
CAGR	Compound Annual Growth Rate
CE	Coulombic Efficiency
CMEM	Comprehensive Modal Emission Model
CO_2	Carbon dioxide
CSP	Constrained Shortest Path
DBDC	Delhi Bus Driving Cycle
DC	Direct Current
DEM	Digital Elevation Mapping
DPM	Double Polarisation Model
ECO-ITS	Eco-friendly Intelligent Transportation System
EECM	Equivalent Electrical Circuit Model
EMF	Electro Magnetic Force
EREV	Extended Range Electric Vehicle
ESR	Equivalent Series Resistance
ESS	Energy Storage Systems
EUDC	European Driving Cycle
EV	Electric Vehicle
EVRP	Electric Vehicle Routing Problem
FAME	Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles
FIFO	First In First Out
FTP	Federal Test Procedure
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicles
ICT	Information and Communications Technology
IMC	Intelligent Motor Controller
IMU	Inertial Measurement Unit
Li-ion	Lithium ion
MEMS	Micro Electromechanical System
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NEDC	New European Driving Cycle
NEMMP	National Electric Mobility Mission Plan
NEV	Neighbourhood Electric Vehicle
NiCd	Nickel Cadmium

NiOOH	Nickel Oxide Hydroxide
NiMH	Nickel Metal Hydride
NN	Neural Network
NO_x	Oxides of Nitrogen
OCV	Open Circuit Voltage
ODE	Ordinary Differential Equation
ORTNS	Optimal Real Time Navigation System
OSM	Open Street Map
P2D	Pseudo 2 Dimensional
PHEV	Plug-in Hybrid Electric Vehicle
PMDC	Permanent Magnet Direct Current
PPR	Pulses Per Revolution
PWM	Pulse Width Modulation
RC	Resistor-Capacitor
RDR	Remaining Driving Range
RDS	On-state Resistance
RPM	Revolutions Per Minute
SLI	Starting,Lighting,Ignition
SoC	State of Charge
SPM	Single Particle Model
UKF	Unscented Kalman Filter
USDC	United States Driving Cycle

List of symbols

ρ_{air}	Density of air (kg/m^3)
F_{drag}	Aerodynamic drag force
C_{drag}	Co-efficient of drag
$A_{frontal}$	Frontal area of EV
f_k	Fuel consumption
v_k	Average speed of traffic
s_k	Road elevation
β_{0-5}	Co-efficient of fuel consumption
E_r	Losses from drag and rolling friction
E_p	Potential energy
F_{roll}	Rolling resistance force
C_{rr}	Co-efficient of rolling resistance
I	Load current
T	Time
C	Capacity of battery
η	Peukert's constant
ω	Angular speed
P_c	Motor power loss in idle mode
M	Moment of force
F_i	Force exerted at location i
R_i	Location
W	Trackwidth
l	Wheelbase
R	Radius of tyre
Cotδ	Cot average of inner and outer steer angles
V	Voltage
R_a	Armature resistance
N	Motor speed
E_b	Back emf of motor
T_a	Armature torque

K_t	Motor torque constant
Ia	Armature current
η_{motor}	Motor efficiency
g	Acceleration due to gravity
m	Vehicle mass
E[k+1]	Additional SoC
E_m	Open circuit voltage
E_{m0}	Open circuit voltage at full charge
R_D(SoC)	Internal resistance during discharge
R_C(SoC)	Internal resistance during charge
E_p	Voltage across capacitance
C_p	Equivalent polarisation capacitance
R_p	Non-linear resistance
Z_w	Warburg impedence
A_w	Warburg co-efficient
f	Frequency
ω_L	Speed of rear left wheel
ω_R	Speed of rear right wheel
ω_{avg}	Average speed of EV
CP	Contact patch
X	Distance between plates
Δd	Distance between the thick and the thin plate
μ	Co-efficient of rolling resistance
θ	Angle of road gradient