DISERTASI

Desain Model *Smart Charging (SC)* Menggunakan Algoritma *Ant Colony Optimization (ACO)* Untuk Menentukan Estimasi *State of Charge (SOC) Lead Acid Battery (LAB)*

Selamat Muslimin
03013682025013

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HALAMAN PENGESAHAN

Desain Model *Smart Charging* (SC) Menggunakan Algoritma *Ant Colony Optimization* (ACO) Untuk Menentukan Estimasi *State of Charge* (SOC) *Lead Acid Battery* (LAB)

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Bidang Ilmu Teknik Elektro

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Dengan ini menyatakan bahwa disertasi Selamat Muslimin yang berjudul "DESAIN MODEL *SMART CHARGING (SC)* MENGGUNAKAN ALGORITMA *ANT COLONY OPTIMIZATION (ACO)* UNTUK MENENTUKAN ESTIMASI *STATE OF CHARGE (SOC) LEAD ACID BATTERY (LAB)*" telah dipertahankan di hadapan sidang ujian tertutup Program Studi Ilmu Teknik Program Doktor, Fakultas Teknik, Universitas Sriwijaya pada tanggal 03 Agustus 2024.

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KATA PENGANTAR

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1. *Review Comparison of Batteries Used in Electrical Vehicles*, diterbitkan dalam *Proceedings of the 5th FIRST T1 T2 2021 International Conference (FIRST-T1-T2 2021), Atlantis Highlights in Engineering*.
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Charging Algorithm Development Based On Ant Colony Optimization Machine Learning For Controlling Lead-Acid Battery Charging Capacity.

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SUMMARY

Design Model of Smart Charging (SC) Using Ant Colony Optimization (ACO) Algorithm to Determine the State of Charge (SOC) Estimation of Lead Acid Battery (LAB).

Scientific Dissertation Research Paper, August 05, 2024
xiii + 109 Pages, 27 Tables, 71 Figures, Bibliography, Attachments

Selamat Muslimin guided by Promoter Prof. Zainuddin Nawawi, Ph.D., and Co-Promoter Dr. Bhakti Yudho Suprapto, S.T., M.T. IPM., Dr. Eng Tresna Dewi, S.T., M.Eng.

Doctor of Engineering Science Study Program, Department of Electrical Engineering, Postgraduate Program, Sriwijaya University

The sub-task of Smart Charging consists of designing a Smart Charging (SC) circuit design tested on 12 Volt/30 Ah and 48 Volt/30 Ah battery types, divided into three stages of testing, namely, Slow Charging (sc), Medium Charging (sc), and Medium Charging (sc). Ah, divided into three stages of testing, namely, Slow Charging (sc), Medium Charging (MC), and Fast Charging (FC), and Fast Charging (FC). At this stage, the SC test is carried out by discharging the State of Charge (SOC) on the battery. on the battery, then charging is carried out by considering the speed, Voltage, Current, power, and battery temperature stability until the SOC is reached again. SOC is reached again. Measurement and scheduling of charging is carried out during the time period of reaching the maximum SOC until the charging system stops. The measurement data is analyzed for each relationship for Voltage, Current, and Power against charging time. charging time by maintaining a stable battery temperature. Research The next stage of the research is to present the design of an integrated Ant Colony Optimization (ACO) algorithm model. Optimization (ACO) algorithm model that is integrated into the Smart Charging model to model to obtain optimal charging results on each battery. Research This research aims to produce Smart Charging using the ACO algorithm. Previous researchers for fast charging batteries focused on lithium-ion batteries. lithium-ion battery applied an improved Elman neural network to form an ACO-Elman neural network model. It was applied to battery SOC prediction. SOC estimation results of ACO-Elman model model is evaluated from three aspects, namely mean absolute error, root mean square error, and SOC error. This study tested four types of lead acid batteries 12 Volt/30 Ah and 48 Volts/30 Ah, to get the prediction results Voltage, current, and power prediction results are stable, and get the maximum SOC and SOH maximum.

Keywords: Smart Charging (SC), ACO Algorithm, Battery

DAFTAR ISI

HALAMAN JUDUL .... **I**
LEMBAR PENGESAHAN .... **II**
KATA PENGANTAR .... **III**
RINGKASAN .... **V**
DAFTAR ISI .... **VI**
DAFTAR TABEL .... **XII**
BAB I PENDAHULUAN **1**
1.1 Latar Belakang 1
1.2 Permasalahan 4
1.3 Hipotesa Penelitian 4
1.4 Tujuan Penelitian 5
1.5 Ruang Lingkup Penelitian 5
1.6 Manfaat Penelitian 5
BAB II TINJAUAN PUSTAKA **6**
2.1 *State of The Art* 6
2.2 *Charging* 10
2.2.1 *State of Charge* (SOC) 11
2.2.2 *State Of Health* (SOH) 12
2.2.3 Metode Pengisian Baterai (*Charging*) 13
2.2.3.1 *Constant Current Charging* 14
2.2.3.2 *Constant Voltage Charging* 14
2.2.3.3 *Constant Current-Constat Voltage* 15
2.2.3.4 *Pulse Method* 16
2.2.3.5 *Reflex Method* 17
2.2.4 Jenis *Charging* 19
2.2.4.1 *Slow Charging* 19
2.2.4.2 *Fast Charging* 20
2.2.4.3 *Switch Mode Power Supply* (SMPS) 20
2.2.4.4 Prinsip Kerja SMPS 20

2.2.4.5 Kelebihan Penggunaan SMPS 21
2.3 DC-DC CONVERTER 21
2.3.1 *Buck Converter* 22
2.3.2 *Boost Converter* 23
2.3.3 *Buck-Boost Converter* 24
2.4 *Pulse Width Modulation* (PWM) 25
2.4.1 PWM Analog 26
2.5 *Machine Learning* (ML) 28
2.5.1 Bidang Cakupan *Machine Learning* [88] 29
2.5.2 Skenario Pembelajaran *Machine Learning* 30
2.5.2.1 *Supervised Learning* (SL) 30
2.5.2.2 *Unsupervised Learning* (UL) 30
2.5.2.3 *Semi Supervised Learning* (SSL) 30
2.5.2.4 *Transductive Inference* (TI) 31
2.5.2.5 *Online Learning* (OL) 31
2.5.2.6 *Reinforcement Learning* (RL) 31
2.5.2.7 *Active Learning* (AL) 32
2.5.3 Penggunaan *Machine Learning* pada Sistem *Charging* 32
2.5.3.1 *Prediction of EV Charging Behavior Using Machine Learning* 32
2.5.3.2 *Modeling of Electric Vehicle Charging Energy Consumption Using Machine Learning* [89] 33
2.5.3.3 E*lectric Vehicles Charging Management Using Machine Learning Considering Fast Charging and Vehicle-to-Grid Operation* ...34
2.6 *Ant Colony Optimization* (ACO) 36
2.6.1 Penggunaan Algoritma ACO pada Sistem *Charging* 37
2.6.1.1 *Electric Vehicle Charging Scheduling Using Ant Colony System*[94] 37
2.6.1.2 Optimalisasi Koloni Semut Hibrida dan Algoritma Lebah untuk Perencanaan Stasiun Pengisian Cepat Umum pada Sistem Distribusi Tenaga Listrik Perumahan [95] 38

2.6.1.3 *Ant Colony Optimization of Charging Coordination of Electric Vehicles Considering Vehicle-to-Grid (V2G) Technology in MultiMicro Grid Power System* 39
2.6.1.4 *Multiobjective Ant Colony Optimization for Fast Charging Stations Planning in Residential Area*[96] 40
2.7 *Fuzzy Logic Controller* (FLC)[97] 41
2.7.1 Fuzzifikasi 42
2.7.2 Inferensi atau Interpretasi 42
2.7.3 Defuzzifikasi 42
2.7.4 Penggunaan *Fuzzy Logic Controller* pada Sistem *Charging* 43
2.7.4.1 Optimized Fuzzy Logic Controller for Responsive Charging of Electric Vehicles[98] 43
2.7.4.2 *Fast Charging Electric Vehicle using Fuzzy Logic Controller* ..44
2.7.4.3 *The Fuzzy-Based Smart Charging Management System for an Electric Vehicle Parking Lot Including a Roof-Top PV System*[100] 45
2.8 *Neural Network* 46
2.9 *Monitoring* 48
BAB III METODOLOGI PENELITIAN 52
3.1 Kerangka Pikir 52
3.2 Perancangan Sistem 54
3.2.1 Perancangan Perangkat Keras (*Hardware*) 56
3.2.2 Desain Model Algoritma *Ant Colony Optimization* (ACO) 60
3.2.3 Perancangan *Flowchart K-Means Clustering* 66
3.3 Pengolahan Data 69
BAB IV HASIL DAN PEMBAHASAN 73
4.1 Hasil Pengembangan Desain Model Smart Charging 73
4.2 Hasil Pengukuran Desain Model Algoritma ACO 77
4.3 Pengujian Final Model Alat 87
4.3.1 Pengolahan Data Menggunakan K-Means Clustering 91
BAB V PENUTUP 110
5.1 Kesimpulan 110
DAFTAR PUSTAKA 111

DAFTAR GAMBAR

Gambar 2.1 Blok Estimasi *State Of Charge* (Soc).. 11
Gambar 2.2 Blok Estimasi *State Of Health* (Soh).. 12
Gambar 2.3 Kondisi Baterai Dengan Nilai Soh Sebesar (A) 100%, (B) 20%. 12
Gambar 2.4 Gelombang Tegangan Dan Arus Pengisian *Constant Current* 14
Gambar 2.5 Gelombang Tegangan Dan Arus Pengisian *Constant Voltage*.......... 15
Gambar 2.6 Gelombang Tegangan Dan Arus Pengisian Cc-Cv 16
Gambar 2.7 Metode pengisian pulsa: a) Rangkaian pengisian pulsa, dan b) Bentuk gelombang arus pulsa……………………………………………………17
Gambar 2.8 Metode Pengisian Refleks: (A) Sirkuit Pengisian Refleks Modern, (B) Sirkuit Pengisian Refleks Konvensional, Dan (C) Bentuk Gelombang Arus Refleks. 18
Gambar 2.9 (A) Rangkaian Dasar Konverter Dc Dc, (B) Rangkaian Mode Switch Chopper 21
Gambar 2.10 Rangkaian *Buck Converter*.. 22
Gambar 2.11 Tegangan Rata-Rata *Buck Converter* 23
Gambar 2.13 Rangkaian Konverter Dc-Dc Tipe Boost + Penyearah Dioda (Faktor Daya Satu) 24
Gambar 2.14 Rangkaian *Buck-Boost Converter* 24
Gambar 2.15 Rangkaian Komparator Dan Bentuk Sinyal Pwm.......................... 26
Gambar 2.16 Rangkaian Pwm Analog... 26
Gambar 2.17 Pembentukan Sinyal Pwm.. 27
Gambar 2.18 Perhitungan *Duty Cycle* Pwm 28
Gambar 2.19 Representasi Grafis Ev *Charging* Yang Diusulkan (Shahriar, Et Al. 2017) 33
Gambar 2.20 Grafik Perbandingan Kurva Beban Pada Situasi Yang Berbeda..... 35
Gambar 2.21 Model *Slow Charging* Di Stasiun Pengisian Rumah Dan Kantor... 39
Gambar 2.22 Dc/Dc Converter Dengan Aco Untuk Managemen Energi 40
Gambar 2.23 Tahapan Utama *Fuzzy Logic Controller* 43
Gambar 2.24 Efisiensi Rata-Rata Pengisi Daya Untuk Pengisian Daya 6 Jam Dan 11 Jam 44

Gambar 2.25 Sirkuit Kontrol Lanjutan Menggunakan Fuzzy Bersama Dengan Kontroler Pid Dan Konverter *Buck-Boost*.. 44
Gambar 2.26 Skema Gambar Smcs 46
Gambar 2.27 Struktur *Neural Network* 46
Gambar 2.28 *Single Layer*.. 47
Gambar 2.29 *Multi Layer* 47
Gambar 2.30 *Reccurent Network* 48
Gambar 3.1 Model *Fast Charging* Dengan Algoritma Aco 53
Gambar 3.2 Diagram Blok Pengolahan Data Dengan *Neural Network (Nn)* 53
Gambar 3.3 *General Research Process* 55
Gambar 3.4 Diagram Model *Fast Charging* Dan Model Baterai 56
Gambar 3.5 Perancangan Diagram Blok Sistem Simulasisoc Dan Dod Pada Motor 700watt.. 56
Gambar 3.6 (A) Diagram Sistem Kendali Aco 57
Gambar 3.6 (B) Diagram Blok *Charging* Model Aco 58
Gambar 3.6 (C) Perancangan Rangkaian *Charging* Model Aco.......................... 59
Gambar 3.7 *Hardware* Pengisian Dengan Sistem Model *Smart Charging* Aco... 60
Gambar 3.8 Jalur Feromone Algoritma *Ant Colonny Optimization Charging* 61
Gambar 3.9 (A) Diagram Alir Sistem *Charging* Dan (B) *Flowchart Aco* 64
Gambar 3.10 (A) *Flowchart* K-Means Cluster Dan (B) *Flowchart* Regresi Linier 69
Gambar 3.11 Tampilan *Google Colab* 70
Gambar 3.12 Tampilan Program *Google Colab* 71
Gambar 4.1 Model *Smart Charging Aco* 73
Gambar 4.2 *Prototype* Model *Smart Charging*.. 73
Gambar 4.3 Sistem Pengujian *Smart Charging* 74
Gambar 4.4. Diagram Alir Cara Kerja *Smart Charging* 75
Gambar 4.5. Diagram Blok Proses Pengambilan Data Saat Pengisian................. 76
Gambar 4.6. Skema *Neural Network* Untuk Proses Estimasi Daya Pada *Rapidminer* 76
Gambar 4.7 Jalur Feromone Soc Algoritma *Ant Colonny Optimization Charging* 77

Gambar 4.8 Grafik Pengukuran *Current* 4 Baterai 81
Gambar 4.9 Grafik Pengukuran *Voltage* 4 Baterai 82
Gambar 4.10 Grafik Pengukuran *Soc* 4 Baterai 83
Gambar 4.11 Grafik Pengosongan Dod Baterai 12 *Volt* 84
Gambar 4.12 Pengujian Soh.. 86
Gambar 4.13 Grafik Tegangan Dan Arus Selama Pengisian Baterai 90
Gambar 4.14 Grafik Soc Selama Pengisian Baterai.. 91
Gambar 4.15 Pengelompokan (A) *K-Means Current* Dan (B) *K-Means Volt*age 91
Gambar 4.16 Pengelompokan *Regresi Linier* Estimasi *Soc*................................ 93
Gambar 4.17. Tampilan Model Jaringan Berdasarkan Hasil Data Pengujian....... 95
Gambar 4.18 Grafik Data Latih Pengisian 12 *Volt* 98
Gambar 4.19 Grafik Data Latih Pengisian 24 *Volt* 99
Gambar 4.20 Grafik Data Latih Pengisian 36 *Volt* 99
Gambar 4.21 Grafik Data Latih Pengisian 48 *Volt* 100
Gambar 4.22. Hasil Pengujian Pengisian Baterai 12 *Volt*.................................. 100
Gambar 4.23 Hasil Pengujian Pengisian Baterai 24 *Volt*.................................. 101
Gambar 4.24 Hasil Pengujian Pengisian Baterai 36 *Volt*.................................. 101
Gambar 4.25 Hasil Pengujian Pengisian Baterai 48 *Volt*.................................. 102
Gambar 4.26 Perbandingan *Voltage, Current Dan Soc* Dengan Dan Tanpa Aco 105
Gambar 4.27 Grafik Perbandingan *Current/Voltage/Soc* Dengan Gs-Pid.......... 106
Gambar 4.28 Hasil Estimasi (Kiri) Dan Pengukuran (Kanan) Soc Menggunakan Issa-Bp [115]... 106

DAFTAR TABEL

Tabel 2.1 Status Sistem Kerja Baterai [46], [47], [48], [49], [50] 7
Tabel 2. 2 *State Of The Art* Penelitian Tentang Estimasi Soc................................ 8
Tabel 2.3 Review Metode *Charging* Untuk Kelebihan Dan Kekurangan 18
Tabel 2.4 *Performance Comparison With Previous Works* 33
Tabel 2.5 *Evaluation Metrics Of All Models* 34
Tabel 2.6 Perbandingan Aco Dengan Pendekatan Lainnya 38
Tabel 2. 7 *Best Solution In Case I*... 40
Tabel 2.8 *Best Solution In Case II* 41
Tabel 2.9 *Best Solution In Case III* 41
Tabel 2.10 Referensi Penelitian 1 49
Tabel 2.11 Referensi Penelitian 2 49
Tabel 2.13 Referensi Penelitian 4 50
Tabel 2.14 Referensi Penelitian 5 50
Tabel 2.15 Data Penelitian 50
Tabel 2.16 Data Penelitian (Lanjutan) 50
Tabel 3.2 Perhitungan Berdasarkan Rumus Aco Jalur Yang Terpilih 62
Tabel 4.2 Perhitungan Berdasarkan Excel Aco Jalur Yang Terpilih 80
Tabel 4.3 Data Soh Pada Baterai... 85
Tabel 4.4 Data Soh Pada Baterai... 87
Tabel 4.5 Hasil Data Pengujian... 89
Tabel 4.6. Data Estimasi Soc Dan Aktual Soc 92
Tabel 4.7 Data Hasil Pengujian... 93
Tabel 4.8. Parameter Pelatihan *Neural Network* 95
Tabel 4.9. Hasil Pengisian Baterai 12 *Volt* 96
Tabel 4.10. Perbandingan Capaian Kecepatan Pengisian 97
Tabel 4.11 Parameter Hasil Pelatihan 98
Tabel 4.12 Data *Ant Colony Optimization* Dan Tanpa *Ant Colony Optimization* 103

Nomenclature

API *Application Programming Interface*

BEV *Battery Electric Vehicle*

BMS *Battery Management System*

C-rate *Discharge current required to fully discharge the battery in one hour*

CAN *Controller Area Network*

CC/CV *Constant Current/Constant Voltage EEC Equivalent Electrical Circuit*

EKF *Extended Kalman Filter*

ESS *Energy Storage System*

EV *Electric Vehicle*

FET *Field Effect Transistor*

GHG *Greenhouse Gas*

GUI *Graphical User Interface*

HEV *Hibrid Electric Vehicle*

I2C *Inter-Integrated Circuit*

IC *Integrated Circuit*

ICE *Internal Combustion Engine*

ISR *Institute of Systems and Robotics*

OBDII *On Board Diagnostic System*

OEM *Original Equipment Manufacturer PID Proportional-Integral-Derivative*

SAR *Successive Approximation Register*

SOC *State of Charge*

SOH *State of Health*

SOL *State of Life*

SPI *Serial Peripheral Interface*

GHG *Green House Gas*

NN *Neural Network*

FCFS *First Come First Serve*

LST *Latest Starting Time*

EDT *Earliest Due Time*

GA *Genetic Algorithm*

PD *Problem Decomposition*

Symbols

a *gear ratio/coupling ratio*

A *frontal surface area of vehicle* [m^2]

B *damping* [kgm^2/s]

c *a constant that considers the bar material and shape*

C *coefficient at vehicles dynamics model*

d *bar depth* [m]

D *duty cycle*

e *electromotive force Voltage* [V]

E *battery Voltage* [V]

f *frequency* [Hz]

F *force* [Nm]

g *gravitational acceleration* [m/s^2]

I *current* [A]

J *moment inertias* [kgm^2]

k *coefficient given by material and design of motor*

L *inductances* [H]

m *total vehicle mass* [kg]

M *modulation index*

n *number of teeth the gear*

N *ratio between switching and fundamental frequency*

p *number of poles in electric motor*

P *the motive power* [W]

Q *capacity of battery* [Ah]

r *radius of wheel* [m]

R *resistance* [Ω]

s *slip of induction motor*

S *snappiness factor for the diode*

T *torque at wheel* [Nm]

v *speed* [m/s^2]

va *relative vehicle speed with respect to the air* [m/s]

V *Voltages* [V]

W *energy* [Wh]

Z *impedance*

δ *specific air density* [kg/m^3]

ω *angular speed* [rad/sec]

Θ *angle position* [rad]

∅ *flux density* [Wb]

α *temperature coefficient*

τ *carrier period* [s]

Subscripts

a *achieved value*

ac *alternating current*

ad *aerodynamic drag*

af *acceleration force*

ave *average values*

c *collector*

cr *climbing resistance*

cu *copper*

cond *conduction*

CE *collector – emitter*

d *developed at electric motor rotor*

dc *direct current*

D *diode*

e *eddy current Fe iron*

g *air gap*

h *hysteresis*

L *load*

m *magnetizing part in electric motor*

mech *mechanical (windage and friction)*

n *harmonics*

o	*open circuit*
on	*on state*
off	*off state*
Q	*power switching device*
r	*electric motor rotor*
rr	*rolling resistance*
rms	*root mean square values*
R	*reverse recovery*
s	*electric motor stator*
sc	*locked rotor*
sw	*switching*
str	*stray*
t	*wheel*
T1	*temperature* T1
T2	*temperature* T2

BAB I
PENDAHULUAN

1.1 Latar Belakang

Kendaraan listrik banyak digunakan oleh masyarakat sebagai kendaraan alternatif yang aman dan rendah polusi. Di Indonesia kendaraan listrik masih diproduksi dan digunakan secara terbatas sebagai kendaraan transportasi perusahaan atau instansi yang sering disebut sebagai *fleet* atau sebagai kendaraan uji [1][2]. Kendaraan listrik digunakan untuk menggantikan kendaraan berbahan bakar minyak bumi (*internal combution engine/ICE).* ICE dinilai dapat membahayakan lingkungan karena menghasilkan pencemaran lingkungan [3]. Kendaraan listrik dapat memberikan dampak signifikan terhadap lingkungan karena secara ekstensif dapat mengurangi emisi gas rumah kaca yang dihasilkan oleh sektor transportasi [4][5]. Tahun 2019 pemerintah Indonesia menerbitkan Peraturan Presiden Nomor 55 tahun 2019 tentang percepatan program kendaraan bermotor listrik jenis *battery electric vehicle* (BEV) untuk transportasi jalan [6].

Diantara jenis mobil listrik lainnya, BEV memiliki efisiensi daya yang paling tinggi [7]. Kendaraan listrik jenis BEV saat ini banyak menggunakan baterai jenis *lead acid (LA), lithium-ion (LI),* dan *lithium-polymer (LP)*. Secara umum, terdapat dua kategori baterai berdasarkan kemampuan pengisian ulang baterai primer dan sekunder, penggunaan baterai kendaraan listrik baterai (BEV) sebagai penyimpanan energi di jaringan listrik (juga dikenal sebagai kendaraan-ke-jaringan listrik (V2G) yang terkait dengan berkurangnya masa pakai baterai karena aktivitas pengisian dan pengosongan yang lebih sering dan penggunaan dalam suhu lingkungan yang tinggi.[11] Baterai primer hanya dapat digunakan sekali setelah dikosongkan, dan baterai sekunder adalah jenis baterai yang dapat diisi ulang setelah proses pengosongan. Kendaraan listrik BEV membutuhkan baterai yang dapat diisi ulang atau baterai sekunder [15], [16], [17]. Selain dapat diisi ulang, baterai sekunder memiliki keunggulan masa pakai yang lama, kehilangan energi yang kecil, kepadatan daya yang tinggi, dan tingkat keamanan yang cukup tinggi [18]. Dalam pemakaian baterai, *State of Charge* (SOC) harus selalu diperhatikan untuk menghindari baterai *over-charge* dan *over-discharge* yang menjadi salah satu penyebab penurunan *state of health* (SOH) baterai. Hal ini menunjukkan diperlukannya pemantauan *State of Charge* (SOC) baterai [19].

Metode pengisian tegangan konstan (*Constant Voltage Charging, (CV))* merupakan metode yang aman digunakan dan meningkatkan kapasitas hingga 20%, tetapi dapat mengurangi efisiensi pada baterai hingga 10% [20] proses pengisian daya EV mengikuti profil pengisian daya nonlinier seperti arus konstan, tegangan konstan (CC-CV). Pengisian daya cerdas harus mempertimbangkan pengisian daya untuk menghindari kesenjangan antara rencana pengisian daya dan konsumsi daya EV yang sebenarnya.[22]. Pada metode tegangan, tegangan pengisian akan tetap konstan dengan arus pengisian tinggi di awal dan secara bertahap turun saat baterai telah mendekati SOC maksimum [23]. Pengisian tegangan konstan tepat digunakan untuk jenis baterai *lead-acid* dan tidak tepat untuk jenis baterai *nickel metal hydride* (*Ni-MH*) atau *lithium-ion* (*Li-Ion).* Hal ini dikarenakan untuk baterai *Ni-MH* dan *Li-ion* lebih disarankan untuk melakukan pengisian secara *CV-CC* [20].

Sebagai pembanding, pengisian arus konstan (*Constant Current,* (*CC)*), merupakan metode yang digunakan untuk melakukan pengisian lebih dari satu baterai[24]. Arus pengisian akan tetap konstan selama periode pengisian [23]. Pada metode ini arus pengisian ditetapkan 10% dari arus yang dibutuhkan. Metode *CC* membutuhkan waktu yang lebih lama untuk mengisi baterai hingga penuh dan saat baterai akan penuh perlu dipantau secara khusus agar baterai tidak mengalami *over Charging* [25]. Kombinasi kedua jenis pengisian tersebut, yaitu tegangan konstan arus konstan (*constant Voltage-constant current, (CV-CC)*), arus dan tegangan dari *charger* akan diatur terlebih dahulu sebelum melakukan pengisian baterai. Metode ini dinilai memungkinkan pengisian cepat tanpa resiko pengisian berlebihan (*Over Charging*) dan cocok untuk berbagai jenis baterai[26].

Klasifikasi waktu pengisian (*Charging)* baterai kendaraan listrik, untuk pengisian daya AC dan DC, dibagi menjadi level 1 dan level 2 (kelas *slow Charging*), level 3 (kelas *fast Charging*)*,* dan *extreme fast Charging* (*XFC*) [27]. Level 1 menghasilkan daya maximum 3,7 KW dengan estimasi pengisian 10-15 jam dan diimplementasikan pada stasiun *Charging* pribadi. Level 2 menghasilkan daya maximum 3,7-22 KW dengan estimasi pengisian 3,5-7 Jam. Level 3 dibagi menjadi dua pengisian AC dan DC. Pengisian AC menghasilkan daya 22-43,5 KW, dan untuk DC menghasilkan daya maximum 200 KW dengan estimasi pengisian 10-30 menit [28][29]. Metode XFC menghasilkan daya minimum 400 KW dengan estimasi pengisian setara pengisian bahan bakar gas.

Saat ini pengisian baterai dikembangkan dengan tetap menjaga estimasi pengisian SOC dan SOH baterai [30]. Pengembangan *fast Charging* diantaranya meliputi penerapan *solid state transformer* (SST), *negative pulse discharge, smart grid with vehicle to grid* (V2G), DC-DC *converter with* PWM *technique,* penerapan komponen *GaN HEMTs + Si MOSFETs,* dan pemanfaatan *effect of rest period and depolarization pulse* [30], pendekatan dan peluang baru yang menjanjikan untuk topologi konverter elektronik daya dan penelitian tingkat sistem untuk memajukan teknologi mutakhir dalam pengisian daya cepat. [31], [32]

Metode yang dipakai untuk pengisian baterai pada penelitian-penelitian sebelumnya cukup bervariasi, dengan salah satunya menggunakan *Ant Colony Optimization* (ACO). Pada tahun 1990 metode ACO diperkenalkan berdasarkan sifat koloni semut mencari sumber makanan [33][34][35]. Sebelumnya metode ACO banyak digunakan pada sistem pengisian baterai cepat *lithium* untuk Hp dengan kapasitas energi yang kecil [36][37]. Pada tahun 2017 metode ACO digunakan juga pada pengisian dengan menggunakan panel surya [38][36]. Penerapan ACO yang merupakan algoritma berdasarkan perilaku semut untuk mencari makan, diterapkan oleh Shivendra Kumar dalam dua langkah. Langkah pertama adalah inisialisasi dan pengaturan populasi semut dari 1 ke n untuk menghasilkan batas maksimum dan minimum variabel. Pada langkah kedua variabel P diambil secara acak antara 0 dan 1, nilai variabel dinaikkan dan dikurangi dengan nilai P. Hasilnya terlihat peningkatan baterai sebesar 0,5% dengan menggunakan baterai 8 Ah. Hal ini mendasari pemilihan solusi untuk penelitian ini, yakni dengan membuat model algoritma ACO sebagai metode pengisian yang cepat, terkontrol, dan cerdas. Sistem kontrol algoritma ACO digunakan untuk mengontrol pengisian daya pada baterai. Solusi ini mencegah terjadinya kerusakan pada baterai karena ketidakseimbangan jumlah muatan yang mengalir di dalam baterai. Ketidakseimbangan tersebut dapat mengakibatkan suhu panas baterai meningkat akibat proses pengisian daya terlalu lama [37][38].

1.2 Permasalahan

Sistem pengisian baterai *fast Charging* sudah banyak digunakan dan dikembangkan. Namun, pengaplikasian tersebut terbatas hanya pada jenis baterai *lithium-ion* [43]. Penelitian sebelumnya menunjukkan bahwa hasil kerja *fast Charging* masih terlampau lama untuk mengisi daya *(charge)* beberapa baterai. *Fast Charging* (FC) yang digunakan menyebabkan baterai menjadi panas, akibatnya umur kinerja baterai menjadi pendek, sementara harga baterai masih sangat mahal. Jenis *Charging* yang digunakan saat ini adalah AC/DC atau DC/DC yang memiliki kelemahan pada peningkatan suhu atau temperatur (T) baterai. Penelitian tentang FC [27] menghasilkan beberapa estimasi waktu pengisian yaitu 10-15 jam menghasilkan daya 3,7 KW; untuk daya maksimum 22 KW diperlukan waktu 3,5 - 7 jam, dan 10-30 menit bisa menghasilkan daya 200 KW. Ini merupakan *research gap* yang menjadi acuan pengembangan penelitian.

Pada penelitian terdahulu diketahui bahwa sistem pengisian cepat FC yang berlebihan dapat mempengaruhi efisiensi dan kapasitas penyimpanan energi mengakibatkan baterai cepat rusak. Berdasarkan kondisi tersebut, penelitian ini berhubungan dengan teknik FC dengan mengembangkan serta mengintegrasikan metode dan model kecerdasan buatan untuk menyelesaikan permasalahan pengisian cepat. Penyelesaian masalah diawali dengan mendesain model rangkaian *FC* dan algoritma ACO, dimana algoritma ACO diaplikasikan untuk mengatasi pengisian pada berbagai jenis baterai memiliki kondisi kapasitas SOC yang berbeda. Dengan demikian rumusan masalahnya Desain model *rangkaian* FC menjadi *Smart Charging* (SC) untuk digunakan ke jenis baterai *Lead Acid* dengan metode estimasi min-max *State of Charge* (SOC) yang terintegrasi ke model algoritma *Ant Colony Optimization* (ACO).

1.3 Hipotesa Penelitian

engacu permasalahan penelitian, *research gap* dan kajian kebaruan penelitian, dapat disusun hipotesis bahwa model algoritma *ant colony optimization (ACO)* bisa menghasilkan kecepatan pengisian baterei secara maksimal dan mempertahankan kestabilan suhu selama proses pengisian. Hal ini mengarah pada peningkatan akurasi estimasi *state of charge (SOC)* baterai.

1.4 Tujuan Penelitian

Untuk memberikan kontribusi sistem pengisian *(charge)* energi baterai pada mobil listrik di Indonesia khususnya di Palembang maka penulis fokus pada penelitian sistem *Smart Charging* (SC). Tujuan dari penelitian ini adalah mengusulkan teknik baru sistem pengisian energi pada baterai kendaraan listrik menggunakan sistem *smart Charging.* Kombinasi solusi matematis dan pemodelan algoritma kecerdasan buatan yang dirancang akan menjadi solusi baru dalam sistem pengisian baterai.

Teknik dan metode baru selama proses pengisian baterai dengan mempertimbangkan SOC dan SOH saat *Charging* dan *disCharging* pada baterai, ditujukan pada:

1. Desain model *Smart Charging (SC)* dengan algoritma ACO untuk menentukan prediksi pemakaian arus pada baterai dan estimasi SOC.
2. Desain model algoritma ACO pada *Smart Charging* untuk mengontrol estimasi kapasitas max-min SOC baterai *lead acid.*

1.5 Ruang Lingkup Penelitian

Ruang lingkup penelitian yang dikerjakan meliputi:

1. Membuat *Hardware Smart Charging* dan simulasi.
2. Menganalisis sistem *Smart Charging* dan menguji hasil data ukur dengan menggunakan MatLab dan Google colab Python.
3. Membuat *syntax Smart Charging* dengan algoritma ACO
4. Menguji *Smart Charging* pada baterai.

1.6 Manfaat Penelitian

Keberhasilan penelitian akan menghasilkan satu sistem *Charging* baru yang *smart* menggunakan algoritma ACO. Sistem ini mampu memprediksi pemakaian arus pada baterai dan mengestimasi kapasitas max-min SOC. Dengan demikian SOH baterai bisa dijaga untuk masa pakai yang lebih baik. Dengan sistem *Charging* yang terestimasi dengan baik, dan memperhatikan SOC-SOH, teknologi *electric vehicle* bisa berkembang lebih baik juga, sehingga isu ramah lingkungan bisa diwujudkan.

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