IMPROVED ANTLION SIZING OPTIMIZATION FOR VEHICLE-TO-GRID CONSIDERING RULE-BASED ENERGY MANAGEMENT SCHEMES

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DEDICATION

To my parents, wife, children, brothers, sisters, and government for their support

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ABSTRACT

Renewable Energy Sources (RESs) integration with Electric Vehicles (EVs) and microgrids has become a popular system for providing an economic and green environment. In order to address power challenges, RESs such as solar and wind are exploited and integrated into a microgrid. EVs play a key role in reducing emissions and energy saving due to their free carbon nature, reducing fuel consumption, and can be used as storage or load. Tripoli-Libya (latitude 32.8872° N and longitude 13.1913° E) located in Northern Africa is one of the oils and natural gas producers that has been selected as the study area. However, the country is bedeviled with electric power problems. Microgrids are faced with planning issues, challenges associated with designing a proper model system, as well as stability which results in low power quality. The issue can be addressed by using metaheuristic algorithms combined with Energy Management Strategy (EMS). However, the conventional metaheuristic algorithms face premature convergence and acquire local optima quickly which needs to be improved. Thus, choosing suitable sizing metaheuristic algorithms is recommended to find the global optimum. Therefore, Improved Antlion Optimization (IALO) coupled with the Rule-Based Energy Management Strategy (RB-EMS) is proposed. An RB-EMS is used to control and monitor the flow of energy in the system using simple mathematical equations. Furthermore, in the literature review, rule-based is recommended due to the decision-making and providing the appropriate result. This study examines a grid-connected system aimed at addressing the current power challenges by integrating RESs into Electric Vehicle Charging Facility (EVCF) using Vehicle-to-Grid (V2G) technology. An objective function for the proposed grid-connected system mainly depends on measuring the per unit of generated electricity as Cost of Energy (COE), and reduction in Losses Power Supply Probability (LPSP) as means of stabilizing the system and maximizing the Renewable Energy Fraction (REF). Mathematical modeling for the Photovoltaic (PV), Wind Turbine (WT), EV, inverter, and Battery (BT) as the microgrid components for the case study (Tripoli-Libya) is adopted. The acquired result has been validated with other algorithms Antlion Optimization (ALO), Particle Swarm Optimization (PSO), and Cuckoo Search Algorithm (CSA). The obtained simulation result indicates that the proposed method IALO contributed lower COE ($0.0936 /kWh), and high REF (99.40%) as compared to the counterpart algorithms. The IALO coupled with RB-EMS fills the gap in sizing and planning a cost-effective system to address the sizing limitations. The results affirm the low-cost nature of the proposed model of a grid-connected microgrid system using V2G technology. A further economic assessment is made using the Stochastic Monte Carlo Method (SMCM) used to estimate the load impact by integrating various numbers of EVs and the payback period. Sensitivity analysis was utilized to demonstrate the impact performance of the proposed components under various scenarios.

ABSTRAK

Integrasi Sumber Tenaga Boleh Diperbaharu (RES) dengan Kenderaan Elektrik (EV) dan mikrogrid telah menjadi sistem yang popular dalam menyediakan ekonomi dan persekitaran hijau. Untuk menangani cabaran tenaga, RES seperti solar dan angin dieksploitasi dan diintegrasikan ke dalam mikrogrid. EV memainkan peranan utama dalam mengurangkan pelepasan dan penjimatan tenaga kerana sifat bebas karbon, mengurangkan penggunaan bahan api, dan boleh digunakan sebagai tempat simpanan tenaga atau beban. Tripoli-Libya (latitud 32.8872° N dan longitud 13.1913° E) yang terletak di Afrika Utara merupakan salah satu pengeluar minyak dan gas asli yang telah dipilih sebagai kawasan kajian. Walau bagaimanapun, negara ini terganggu dengan krisis bekalan kuasa elektrik. Mikrogrid berhadapan dengan isu perancangan, cabaran yang berkaitan dengan mereka bentuk sistem model yang sesuai, serta kestabilan yang menyebabkan kualiti kuasa yang rendah. Isu ini boleh ditangani dengan menggunakan algoritma metaheuristik yang digabungkan dengan Strategi Pengurusan Tenaga (EMS). Walau bagaimanapun, algoritma metaheuristik konvensional mengalami masalah pramatang dan memperoleh optimum setempat dengan cepat yang perlu dipertingkatkan. Oleh sebab itu, memilih saiz algoritma metaheuristik yang sesuai adalah disyorkan untuk mencari tahap optimum global. Oleh itu, Pengoptimuman Antlion Dipertingkat (IALO) bersama dengan Strategi Pengurusan Tenaga Berasaskan Peraturan (RB-EMS) dicadangkan. RB-EMS digunakan untuk mengawal dan memantau aliran tenaga dalam sistem menggunakan persamaan matematik mudah. Tambahan pula, dalam kajian literatur, berasaskan peraturan disyorkan kerana membuat keputusan dan memberikan hasil yang sesuai. Kajian ini mengkaji sistem tersambung grid yang bertujuan menangani cabaran kuasa semasa dengan mengintegrasikan RES ke dalam Fasiliti Pengecasan Kenderaan Elektrik (EVCF) menggunakan teknologi Kenderaan ke Grid (V2G). Fungsi objektif untuk sistem tersambung grid yang dicadangkan terutamanya bergantung pada pengukuran per unit elektrik yang dijana sebagai Kos Tenaga (COE), dan pengurangan Kebarangkalian Kehilangan Bekalan Kuasa (LPSP) sebagai cara menstabilkan sistem dan memaksimumkan Pecahan Tenaga Boleh Diperbaharu (REF). Pemodelan matematik untuk Fotovoltaik (PV), Turbin Angin (WT), EV, penyongsang dan Bateri (BT) sebagai komponen mikrogrid untuk kajian kes (Tripoli-Libya) digunakan. Hasil yang diperoleh telah disahkan dengan algoritma lain iaitu Pengoptimuman Antlion (ALO), Pengoptimuman Kelompok Zarah (PSO), dan Algoritma Carian Cuckoo (CSA). Hasil simulasi yang diperoleh menunjukkan bahawa kaedah IALO yang dicadangkan menyumbang COE yang lebih rendah ($0.0936/kWh), dan REF yang tinggi (0.9940%) berbanding dengan algoritma lawan. IALO yang diganding dengan RB-EES mengisi jurang dalam saiz dan merancang sistem yang kos efektif untuk menangani had saiz. Keputusan mengesahkan sifat kos rendah model cadangan bagi sistem mikrogrid tersambung grid menggunakan teknologi V2G. Penilaian ekonomi selanjutnya dibuat menggunakan Kaedah Stokastik Monte Carlo (SMCM) yang digunakan untuk menganggarkan kesan muatan dengan menyepadukan pelbagai nombor EV dan tempoh bayaran balik. Analisis sensitiviti digunakan untuk menunjukkan prestasi impak komponen yang dicadangkan di bawah pelbagai senario.

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LIST OF ABBREVIATIONS

ABC - Artificial Bee Colony
AD - Autonomy days
ACO - Ant Colony Optimization
AEV - All-Electric Vehicle
AI - Artificial Intelligent
ALO - Antlion Optimizer
ASC - Annualized System Cost
BAN - Building Area Network
BT - Battery
CO_2 - Carbon Dioxide
COE - Cost of Energy
CRF - Cost Recovery Factor
CSA - Cuckoo Search Algorithm
CSERS - Center for Solar Energy Research and Studies
DCF - Discounted Cash Flow
DP - Dynamic Programming
DoD - Depth-of-Discharge
ECMS - Equivalent Consumption Minimization Strategy
EV - Electric Vehicles
EVCS - Electric Vehicle Charging Station
EVCF - Electric Vehicle Charging Facility
EMS - Energy Management Strategy
ESS - Energy Storage Systems
FA - Firefly Algorithm
FC - Fuel Cell
G2V - Grid-to-Vehicle
GHG - Greenhouse Gas
GA - Genetic Algorithm
GECOL - General Energy Company of Libya
GOA - Grasshopper Optimization Algorithm

GWA	-	Ground Water Authority
GWO	-	Gray Wolf Optimization
HAN	-	Home Area Network
HOMER	-	Hybrid Optimization Model for Electric Renewable
HRES	-	Hybrid Renewable Energy Source
HEV	-	Hybrid Electric Vehicle
IALO	-	Improved Antlion Optimization
ICEV	-	Internal Combustion Engine Vehicles
iHOGA	-	Integrated Hybrid optimization by Genetic Algorithm
IPT	.	Inductive Power Transfer
LAEC	-	Libya Atomic Energy Corporation
LF	-	Lévy Flight
Li-ion	-	Lithium-ion
LiFePO4	-	Lithium-iron Phosphate
LOA	-	Lion Optimization Algorithm
LPSP	-	Losses Power Supply Probability
LREA	-	Libyan Renewable Energy Authority
MPC	-	Model Predictive Control
MOPSO	-	Multi-Objective Particle Swarm Optimization
MOSaDE	-	Multi-objective self-adaptive differential evolution
MO	-	Multi-Objective
NAN	-	Neighbourhood Area Network
NECL	-	National Energy Council of Libya
NFL	-	No Free Lunch
NiCD	-	Nickel-Cadmium
NiMH	-	Nickel-Metal Hydride
NOC	-	National Oil Committee
O&M	-	Operation and Mantineans
OB	-	Optimization-Based
PHEV	-	Plug-in Hybrid Electric Vehicle
PV	-	Photovoltaic
PMP	-	Pontryagin’s Minimum Principle
PSO	-	Particle Swarm Optimization

RB - Rule-Based
RE - Renewable Energy
REF - Renewable Energy Fraction
RESs - Renewable Energy Sources
REAOL - Renewable Energy Authority of Libya
RS - Renewable Sources
SA - Simulated Annealing
SDG7 - Sustainable Development Goal Seven
SFO - Sun Flow Optimization
SG - Smart Grids
SO - Single-Objective
SoC - State-of-Charge
TNPC - The Total Net Present Cost
UN - United Nations
UPS - Untreatable Power Supply
V - Volt
V2B - Vehicle-to-Building
V2D - Vehicle-to-Device
V2G - Vehicle-to-Grid
V2H - Vehicle-to-Home
V2I - Vehicle-to-Infrastructure
V2L - Vehicle-to-Load
V2N - Vehicle-to-Network
V2P - Vehicle-to-Pedestrian
V2V - Vehicle-to-Vehicle
V2X - Vehicle-to-Everything
WPT - Wireless Power Transfer
WT - Wind Turbine

LIST OF SYMBOLS

Ah - Ampere hour

$\mathrm{Antlion}_j^t$ - Position of antlion

Ant_i^t - Position of ant

C_B - The battery capacity (Ah)

C_{grid} - The buying cost of power

C_{PV} - The cost of the solar panels

C_{SOL}^{INST} - The installation cost of the solar

C_{SOL}^{REP-C} - The replacement cost of the solar

$C_{SOL}^{O\&M}$ - The annual maintenance cost of the solar

C_{WT} - The cost of the wind turbine

C_{WT}^{INST} - The installation cost of the wind turbine

C_{WT}^{REP-C} - The replacement cost of the wind turbine

C_{WT}^{M} - The annual maintenance cost of the wind turbine

C_{BATT} - The cost of the battery

C_{BT}^{INST} - The installation cost of the battery

C_{BT}^{REP-C} - The replacement cost of the battery

C_{BT}^{M} - The annual maintenance cost of the battery

C_{INV} - The cost of the inverter

C_{INV}^{INST} - The installation cost of the inverter

C_{INV}^{REP-C} - The replacement cost of the inverter

C_{INV}^{M} - The annual maintenance cost of the inverter

$C_{\mathrm{bat}}^{\mathrm{EV}}$ - EV capacity

$P_{EV_{Dem}}$ - EV power demand

$E_{grid(selling)}$ - The selling energy

$E_{grid(purchased)}$ - The purchasing energy

E_{served} - Primary load served

E_L - Load demand

EV_{demand} - Electric vehicle demand

E_{grid} - Energy from grid

G_t - Solar irradiance

H - Hub height

$\mathrm{h}_{\mathrm{ref}}$ - The reference height anemometer

i - Annual interested rate

M_{Ant} - The saving position of ants

M_{OA} - The fitness function of ant

$M_{AntLion}$ - The saving position of antlion

M_{OAL} - The fitness function of antlion

N_{PV} - Number of solar panels

N_{WT} - Number of wind turbines

N_{BATT} - Number of batteries

NPC_x - Net present cost

P_r - Rated power

PV_{rated} - Rated power for PV

P_{BT} - Power delivered from the battery

P_l - Power of load demand

$P_{\mathrm{P}}^{\mathrm{grid}}$ - The amount of purchased energy from the grid to EV

$P_S^{\mathrm{grid}}(\mathrm{t})$ - The amount of energy sold from the EV to the grid

P_l^m - The peak load demand

P_{inv} - The inverter rating power

P_{PV} - Output power from the photovoltaic

P_{WT} - Output power from wind turbine

R_{grid} - Revenue from selling energy to the grid

$rate_{feed-in}$ - Feed-in tariff rate

SOC_{BT} - State-of-Charge of the battery bank

$\mathrm{SOC}_{\mathrm{EV}}$ - State-of-Charge of EV battery

T - The difference between the arrival and departure times

T_{amb} - Ambient temperature

$T_{\mathrm{Arrive}}^{\mathrm{EV}}$ - The arrival time of electric vehicles

$T_{C_{STC}}$ - Cell temperature

T_{Dep}^{EV} - The departure time of electric vehicles

v_{ref} - Wind speed

v - Rate turbine

v_r - Rated wind speed

v_{cut-in} - Cut-in wind speed

$v_{cut-out}$ - Cut-out wind speed

σ - Self-discharge rate

η_b - Battery efficiency

η_{inv} - Inverter efficiency

α_{step} - Step size in lévy flight

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

The grid-connected or on-grid system is a system considering Renewable Energy Sources (RESs) integrated with the utility grid to form a microgrid or hybridize system [1]. The significant difference between the microgrid and grid-connected system is, that a microgrid can be used as a support to an on-grid system to overcome conventional power limitations [2]. Besides, all available sources in the literature are in agreement that a cluster of loads can be termed a microgrid system [3]. Additionally, microgrid sources operate as a controllable scheme that provides heat, power, or both [4]. In terms of classification, a hybrid system can be categorized into two categories: grid-isolated and grid-connected [5]. Hence, a microgrid system is preferable because of its merits such as flexibility and efficiency [6]. Due to the increasing environmental concerns coupled with the increase in electricity demand among consumers, alternative energy sources are being utilized globally among scholars. Moreover, the hybrid system can address source and load problems in comparison with the traditional network [7].

Under the concept of Vehicle-to-Grid (V2G) as an accepted technology, the utility grid as an unlimited energy source is used to charge Electric Vehicles (EVs) [8]. The EV as a high-tech technology can absorb or distribute energy which is known as a charge or discharge operation [9]. This is because of the provided benefits such as simplicity, use as a mobile Uninterruptible Power Supply (UPS), and easily of plugging and play capability [10]. The V2G technology was pioneered by Amory Lovins in 1995 and carried out by William, EV is recognized as a possible and alternative solution to power and environmental problems [11]. The concept behind V2G is to enable to push of the power from the EV to the grid to balance the variations in energy production and consumption through a bidirectional converter [12].

Furthermore, when the load demand from the utility grid is high, the stored energy in the EV battery can be fed back to the utility grid (V2G) [13]. On the contrary, Grid-to-Vehicle (G2V) is when the grid load demand is low with the price, the unutilized energy from the utility grid can be sent back to the EV to avoid waste of energy [14]. Demand and supply must be balanced to support power transmission and keep the grid reliable [15]. Some of the acquired benefits of V2G technology can be better frequency control, stabilizing the grid operation in peak hours, lowering voltage fluctuation, and exchanging power among others [16].

In addition, ancillary services like peak shaving, load leveling, frequency and voltage regulation, and spinning reserve are counted as V2G benefits [17]. Nevertheless, RESs exploitation is classified under the ancillary services due to the green energy and supported power provided to the main grid [18]. Consequently, microgrid systems known as Smart Grids (SGs) are considered the future power solution. This is due to their intelligent used systems and components used capability such as integration with vehicles in Electric Vehicle Charging Station (EVCS) application and RESs [19]. There are four types of EVCS which are: grid-connected EVCS, EVCS with RESs, grid-connected EVCS with battery, and grid-connected with both RESs and battery [6]. This study considers residential grid-connected EVCS with RESs and Battery (BT) as the main concentration of microgrid systems under the domestic Electric Vehicle Charging Facility (EVCF) that refers to the home-based charger by utilizing home facilities to charge the EV. The last mentioned type has been chosen due to its merits such as reducing the electricity bill, better performance, and reducing the burden on the grid [20], [21]. Additionally, the use of RE requires less maintenance and prevents a spike in pricing [22].

The microgrid is comprised of the interconnection of numerous sources and systems that are connected such as Photovoltaic (PV), Wind Turbine (WT), and Fuel Cell (FC) [23]. The first two mentioned sources are considered to reduce the emission, reduce the impact on the grid, reduce the dependency on the grid, and satisfy the load demand [24]. Additionally, the integration of various energy sources can complement the drawbacks attributed to the use of an individual source. Energy Storage Systems

(ESSs) is a backup system or storage used in EVs to exchange the stored energy with the grid as V2G technology as demonstrated in Figure 1.1.

The straight black arrows in Figure 1.1 represent the power flow while the blue dots arrows refer to the communication and control lines. Residential AC load is realized with the help of converters and rectifiers to change the power form [16]. The presented grid-connected diagram consists of PV-WT-Inverter-BT integrated with EV. The aforementioned components are mathematically modeled to estimate the output power for each part to satisfy the load demand as will be presented in chapter 3 [21]. Due to the energy consumption of fossil fuels, new research windows are being explored by scholars to develop and implement a RESs integrated grid system to overcome power loss-related issues [25]. However, RESs are affected by weather conditions, while the integration operation can bring impact on the grid either positively or negatively [10]. In any case, if the two sources are optimally linked, the effect on the RESs can be partially fixed, resulting in a capable and cost-effective comprehensive system [26].

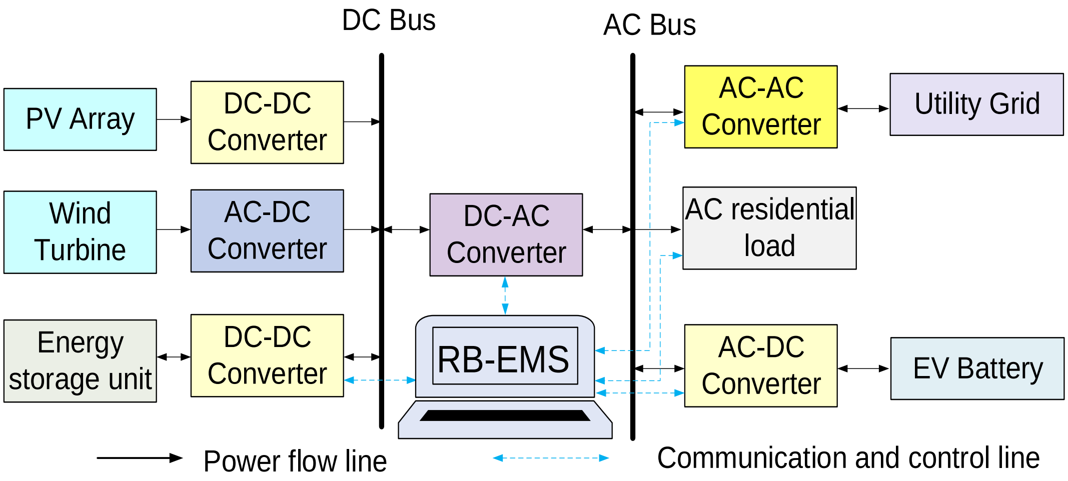

Figure 1.1 The typical energy management strategy for microgrids.

The effect of the implementation process can be regulated with supervisory control optimization methods known as Energy Management Strategy (EMS). The EMS is classified into three main categories: Rule-Based (RB), Optimization-Based (OB), and Learning-Based (LB) as reported in the literature [16], [27], [28]. In this regard, the feasibility of resources, cost, losses, and renewability is reliant on EMS.

One of the issues faced by the microgrid system is planning and designing a model system. Besides, there are several promising optimization algorithms were introduced to regulate power flow in the systems and used with the potential to ease the electricity generation operation [1].

The algorithms were created with the hybrid designed systems based on mathematical modeling equations that are factored in EMSs [29]. The EMS is used to conduct the combined system through the use of nature-inspired metaheuristic algorithms such as Ant Colony Optimization (ACO) [30] and Genetic Algorithm (GA). Additionally, Particle Swarm Optimization (PSO) [31], Cuckoo Search Algorithm (CSA) [32], and Antlion Optimization (ALO) [33] are also used. Nevertheless, the aforementioned optimization methods are not all suitable for solving power sizing problems and other issues as the No Free Lunch (NFL) theorem stated [34]. In addition, some of the studies considered in the literature utilize nature-inspired metaheuristic algorithms coupled with the EMS to control the flow energy among the other parameters [35]. The system of this study consists of RESs integrated into the national grid to charge and discharge EVs to form V2G technology. However, the integration system causes some challenges.

1.2 Problem Statement

With the availability of conventional sources (oil and natural gas) and the current low prices of these sources, conventional energy sources are widely used for electricity generation compared to RESs. Conventional sources and RES have the ability to be hybridized to run electric appliances and charge EVs. The integration of EVs in the hybridized system can address the power limitation issues, however, this increases the load due to having an uncertain number of EVs. Moreover, the use of alternative energy sources reduces the over-dependency on fossil fuels, reduces the peak load demand on the residential side, and overloading-related issues. However, integrating different RES would increase the system's cost and complexity. Metaheuristic sizing algorithms are facing challenge in achieving local optima, premature convergence, and running time speed. Additionally, controlling the power flow needs a suitable control algorithm like the EMS algorithm. However, EMS is requiring technical information and some is requiring complex mathematical equations. Therefore, a proper adoption of EMS and sizing techniques in the hybrid power system becomes significantly important in identifying the most suitable capacity of the system components. Although there have been several techniques used to manage the existing power system, yet, some difficulties on the energy supply side due to improper management such as overloading remain a challenge. The aforementioned issue can be possibly addressed by scheduling a time for charging the EVs when the load of the utility grid is low (G2V) considering conventional or RESs. In general, Hybrid Renewable Energy Source (HRES) systems are reported to be efficient, economical, flexible, and cost-effective to overcome power management problems. The main advantages of HRES integration as a suitable system for stabilizing electric systems and improving power quality. Nevertheless, integrating HRESs into the utility grid faces challenges and issues related to the end-user side due to an increase in peak load demand which leads to the high cost of the system. The use of RESs in EV charging stations lowers the Cost of Energy (COE) and Losses of Power Supply Probability (LPSP) while maximizing the Renewable Energy Fraction (REF). Hence, reducing the cost and losses to gain an economic and reliable system while maximizing the renewability to reduce the dependency on the utility grid to obtain an economic system is needed. Additionally, economic and reliable performance are paired factors that restrict each other, which are also affected by the performance of the decision-maker.

The unplanned V2G process results in instability, inefficiency, and increase COE and unreliability that causes power barriers (overloading). Nevertheless, controlling and planning a proper design for the V2G system with RESs (RESs-EV) is a matter of technical and economic perspective. However, some of the worrying barriers of RESs for power system when used in the EV integration system for their intermitted nature and fluctuation in the power supply which leads to high penetration of EVs when using a huge number of EVs which causes power challenges in terms of loading and power quality. Thus, low power quality caused overload due to the uncertain number of charging vehicles in the charging area and an increase in COE. Similarly, difficulties faced in planning and designing such a system includes unstable weather condition and unknown load demand. Therefore, if RESs and EVs are integrated carefully, a balanced power grid resulting in lower energy costs, and less reliance on conventional sources (fossil fuel) can be ensured. In addition, Carbone Dioxide (CO_2) emissions can be significantly reduced, which ultimately increases the system's reliability. Hence, adopting proper EMS and system sizing to guarantee the lowest investment cost for the system becomes necessary. Additionally by analysing the obtained economic result by the stochastic method in order to assess the impacts on the load from the EV.

1.3 Research Objectives

This research aims to propose a suitable EMS for the proposed microgrid consisting of PV-WT-BT connected to an electric vehicle charging facility. As a residential grid-connected system to achieve the following objectives:

1. To design a deterministic Rule-Based EMS to satisfy the load demand of a residential grid-connected system consisting of PV-WT-BT integrated with V2G technology.
2. To optimize the sizing of the proposed microgrid system using the Improved Antlion Optimization (IALO) to meet load demand at minimum COE, minimum LPSP, and maximum REF.
3. To compare and analyse the proposed components with ALO, PSO, and CSA in terms of COE, LPSP, and REF.

1.4 Scope of the Study

The main aims of the study are to size the system components by developing a metaheuristic algorithm for residential areas integrated into EVs to charge and discharge using PV-WT-BT. The subsequent scopes are considered:

(a) This study is focusing on designing and proposing a sizing optimization metaheuristic method namely Improved Antlion Optimization (IALO) as a variant of ALO to optimize the microgrid with the utilized components. The attained result will be validated with ALO, PSO, and CSA.

(b) Solar and wind energy sources are considered the main RESs in this study, due to their availability in the study location (Tripoli-Libya). While storage battery used as a backup integrated with an EV is used to supply an AC residential load (220 V and 50 Hz) when needed. The solar PV module used in the study is installed on the rooftop of the houses. While the WT is owned by the government and installed away from the residential area.

(c) The objective functions of the study are to minimize the Cost of Energy (COE) and Losses of Power Supply Probability (LPSP) while maximizing the renewability which is called Renewable Energy Fraction (REF) to gain a cost-effective system.

(d) The simulation concentrates on the domestic load using the implemented RESs (PV with 5 kW and 5 kW for WT) integrated with Lithium-iron Phosphate ($LiFePO_4$) 40 Ah EVs battery capacity and Li-ion deep cycle battery. Linked to the grid as a power source for charging and discharging that is based on the Libyan energy policy and Tripoli climatology data. The size of the charging station ranges between 10 to 60 EVs and can be extended to a flexible system or minimized and has been controlled by RB-EMS and the impact on the load for the arrival and departure EVs is estimated by Stochastic Monte Carlo Method.

(e) The lifetime of the project is set as the PV age (25 years). Where components' (WT, BT, and inverter) age is 25, 10, and 15 years, respectively. The annual (1st January to 31st December 2019) hourly residential electricity demand data of 7.5 kW for Tripoli-Libya (latitude 32.8872° N and longitude 13.1913° E) was obtained from the General Electricity Company of Libya (GECOL). While climate data (wind speed, ambient temperature, and solar radiation) were collected from the Centre for Solar Energy Research and Studies (CSERS), accordingly.

(f) The proposed system is simulated with MATLAB 2016b packaging code simulation and does not require any hardware implementation.

1.5 Significance of the Study

The contribution of this research is highlighted for the proposed microgrid hybrid system as stated below:

a) Addressing the microgrid components sizing by the proposed metaheuristic algorithm called IALO for a residential grid-connected system consisting of PV-WT-BT integrated with EVCF to form V2G technology.

b) Utilizing a supervisory control algorithm namely a Rule-Based Energy Management Strategy (RB-EMS) for controlling the flow of power in the system under four strategies. The strategies are supply system from RESs, supply system by BT, charging EVs using G2V, and discharging from EVs using V2G.

c) Utilizing the Stochastic Monte Carlo Method (SMCM) to estimate the arrival and departure behavior of several EVs in the EVCF along with measuring the EV impact on the grid considering different sources. The sensitivity analysis is conducted to assess the COE of the main key affected sources.

d) Assessing the COE in order to obtain the DPP based on the combination of DCF, and the statistic calculation of the payback period is performed for economic analysis.

1.6 Research Methodology

This section is a brief overview of the proposed methodology of the research and the techniques applied to obtain the research objectives. It is divided into several main tasks as shown in Figure 1.2 and further details on the methodology are presented in chapter 3.

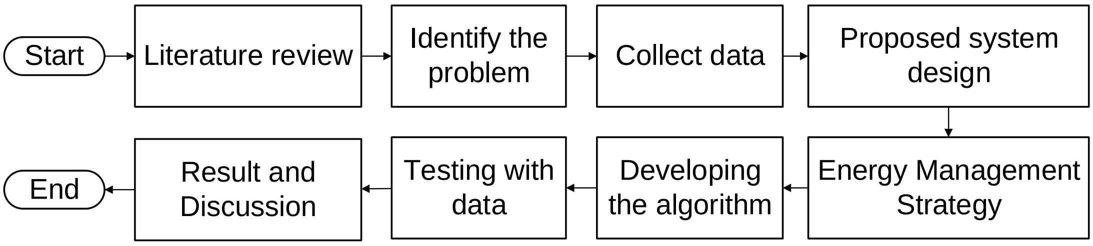

Figure 1.2 The proposed research methodology.

To establish a well understanding of the hybrid systems, a literature review becomes necessary. Literature on different metaheuristic algorithms, EMS algorithms, and RESs from various articles was carried out. The main aim of reviewing the articles is to have a good understanding of the hybrid systems with their components in addition to knowing their strengths and limitations. In this context, priority is given to quartile journals, high-impact factor journals, and indexed journals in Scopus.

As the study area (Tripoli-Libya) has four seasons, the climatology data and load demand for the area of study are required to be collected. To apply the mathematical equations to obtain the total generated power in each season with the help of solar irradiance (G), ambient temperature (T_{amb}), and wind speed (v) sourced from CSERS for one year (1st January to 31st December 2019) [7], [36]. Additionally, the load demand (P_l) for the area of study was obtained from GECOL [37].

Components such as PV-WT-BT integrated with EV are used to form the V2G technology as a grid-connected. The IALO is a sizing method used for the utilized components to provide a system with less cost and losses. In this research, a rule-based EMS algorithm is used to present the entire system operation mode and control the flow of power. Moreover, SMCM is exploiting to assess the impact behavior of arrivals and departure EVs to home. The utilized mathematical equations are widely used among scholars due to their simplicity and cover all the system components.

The results obtained from the IALO are benchmarked with ALO, PSO, and CSA algorithms as the most operating algorithms for a vast range of real-world problems. Additionally, in terms of EMS results, the obtained result from the RB-EMS-IALO is validated with RB-EMS-ALO, RB-EMS-PSO, and RB-EMS-CSA. The

RB-EMS-IALO performance has been investigated based on proposed objective functions (COE, LPSP, and REF) and provides a better result. In terms of economic analysis of the cost, the Discounted Cash Flow (DCF) is utilized with Net Present Cost (NPC) to obtain the Discounted Payback Period (DPP) of the system. Followed by sensitivity analysis results. Eventually, the results will be discussed, and the research is concluded.

1.7 Organization of Thesis

This thesis is organized into five chapters. Chapter 1 contains a general overview of the study, the problem statement, research objectives, the scope and significance of the study, and a brief explanation of the methodology.

Chapter 2 presents the literature review on different EMS considering different energy sources and a hybrid system. Classification of the EMS using metaheuristic sizing algorithms is also discussed. Furthermore, optimal sizing methods, their classifications, and applications-based nature-inspired metaheuristic algorithms are presented. Additionally, the classification of EVs is based on V2G technology with the impacts. A comprehensive review of research studies presenting the use of RES integration with the EVs forms the V2G technology with different objectives is discussed.

Chapter 3 presents the research methodology with the proposed hybrid microgrid system for the case study considering the mathematical simulation modal for each sector in the considered hybrid system. The analysis of climatology and load collected data for the considered location has been analyzed using MATLAB software. The utilized supervisory control scheme (RB) is figured out with the operational strategies.

Chapter 4 presents the simulation and analysis of the climate data and load demand profile. The Chapter also presents and compares the sizing result of the proposed method (IALO) with other results from ALO, PSO, and CSA. Similarly, the result obtained from the EMS algorithm of the proposed algorithm (RB-EMS-IALO) is benchmarked with other algorithms (RB-EMS-ALO, RB-EMS-PSO, RB-EMS-CSA) and presented in this chapter. The compared results of the utilized test functions are also discussed. The comparison convergence curves for the proposed and benchmark methods are figured out and discussed in terms of cost. Consequently, the Dynamic Payback Period (DPP) analyzed using Discounted Cash Flow (DCF) analysis method is presented. Similarly, the Stochastic Monte Carlo Method implementation is used for estimating the behavior of EVs under various scenarios. The considered scenarios present the impact on the grid when having a minimum (10) units, medium (30) units, and maximum (60) units a number of EVs integrated into the grid. The obtained result of the aforementioned scenarios is also demonstrated and discussed along with the sensitivity analysis.

Chapter 5 concludes the thesis and lists the contribution of the proposed work is highlighted. Moreover, suggestions for future work areas are listed for scholars.

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LIST OF PUBLICATIONS

1. **A. Alsharif**, C. W. Tan, R. Ayop, K. Y. Lau, and A. M. Dobi, “A rule-based power management strategy for Vehicle-to-Grid system using antlion sizing optimization,” J. Energy Storage, vol. 41, no. July, p. 102913, Sep. 2021, doi: 10.1016/j.est.2021.102913. (**ISI: Q1-IF:8.907 (Published)**).
2. **A. Alsharif**, C. W. Tan, R. Ayop, A. Dobi, and K. Y. Lau, “A comprehensive review of energy management strategy in Vehicle-to-Grid technology integrated with renewable energy sources,” Sustain. Energy Technol. Assessments, vol. 47, no. January, p. 101439, Oct. 2021, doi: 10.1016/j.seta.2021.101439. (**ISI: Q2-IF: 7.632** (**Published**).
3. **A. Alsharif,** C. W. Tan, R. Ayop, A. Ali Ahmed, F. H. Kuwil, M. Mohamed Khaleel. Impact of Electric Vehicle on Residential Power Distribution Considering Energy Management Strategy and Stochastic Monte Carlo Algorithm. Energies, pp. 1–24, 2023, doi: 10.3390/en16031358**. (Q1, IF: 3.252 (Published)**
4. **A. Alsharif**, C. W. Tan, R. Ayop, K. Y. Lau and C. L. Toh, "Sizing of Photovoltaic Wind Battery system integrated with Vehicle-to-Grid using Cuckoo Search Algorithm," *2021 IEEE Conference on Energy Conversion (CENCON)*, 2021, pp. 22-27, doi: 10.1109/CENCON51869.2021.9627291. (**Indexed by SCOPUS-Published).**
5. **A. Alsharif**, C. W. Tan, R. Ayop, A. Ali Ahmed, M. Mohamed Khaleel and A. K. Abobaker, "Power Management and Sizing Optimization for Hybrid Grid-Dependent System Considering Photovoltaic Wind Battery Electric Vehicle," *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, 2022, pp. 645-649, doi: 10.1109/MI-STA54861.2022.9837749. **(Indexed by SCOPUS-Published).**
6. **Alsharif, A**., Tan, C. W., Ayop, R., Hussin, M. N., & Bukar, A. L. (2022). Sizing Optimization Algorithm for Vehicle-to-Grid System Considering Cost and Reliability Based on Rule-Based Scheme. *ELEKTRIKA- Journal of Electrical Engineering, 21*(3), 6–12. https://doi.org/10.11113/elektrika.v21n3.353 **(Indexed by SCOPUS Published)**