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MULTI-OBJECTIVE SIZING OPTIMIZATION OF STAND-ALONE PHOTOVOLTAIC-RETIRED ELECTRIC VEHICLE BATTERY-HYDROGEN-DIESEL GENERATOR SYSTEM USING MODIFIED HONEY BADGER ALGORITHM

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ABSTRACT

Stand-alone photovoltaic (SAPV) systems offer sustainable and reliable electricity solutions for remote areas. However, achieving a technically and economically optimized system remains challenging without accurate system sizing due to the exclusion of detailed component dimensioning and accurate model selection in existing optimization methods. In addition, many existing meta-heuristic algorithms are prone to convergence issues caused by an imbalance in their exploration and exploitation parameter. Moreover, single sizing objective, which optimize either technical reliability through Loss of Power Supply Probability (LPSP) or economic performance through Levelized Cost of Energy (LCOE), fail to capture the trade-offs in hybrid energy systems. Furthermore, commonly used energy storage technologies such as lead-acid and lithium-ion batteries are hindered by reliability and cost concerns. To address these limitations, this thesis presents "Multi-Objective Sizing Optimization of Stand-Alone Photovoltaic-Retired Electric Vehicle Battery-Hydrogen-Diesel Generator System using Modified Honey Badger Algorithm". The objectives are 1) to develop a Modified Honey Badger Algorithm (MHBA)-based sizing algorithm for single-objective optimization, targeting either minimizing LPSP or LCOE in AC coupled stand-alone photovoltaic-lead acid battery-diesel generator system, 2) to develop a multi-objective MHBA-based sizing algorithm for simultaneous optimization of LPSP and LCOE in AC coupled stand-alone photovoltaic-lead acid battery-diesel generator system, and 3) to evaluate the LPSP and LCOE in AC coupled stand-alone photovoltaic-diesel generator system with retired electric vehicle battery (REVB) and hydrogen system as the energy storage. A rural school in Kota Marudu, Sabah was served as the case study, with hourly load profile and meteorological data collected over 12 months. Component models for photovoltaic modules, batteries, hydrogen storage, inverters and diesel generator were selected based on the technical database and simulated in MATLAB. The study assumes ideal performance of refurbished REVB. The optimization problems were formulated to minimize LPSP and LCOE subject to constraints on energy balance and component models availability. The MHBA was enhanced by modifying its density factor parameter to improve exploration-exploitation balance. In single-objective optimization, MHBA achieved an LPSP of 0.0026 and an LCOE of RM 0.5269 per kWh, with elapsed times up to 100 times faster than a benchmark iterative sizing method. In multi-objective optimization, the reference point-MHBA generated 19 Pareto optimal solutions with strong convergence and diversity, showing up to 62.17% better convergence and 806.57% higher diversity compared to other methods. Subsequently, comparative analysis of four different configurations showed the effectiveness of hybrid storage integration, where PV–REVB–hydrogen–diesel system achieved the lowest LPSP of 1.99×10^{-4} with a competitive LCOE of RM 0.5436 per kWh. Sensitivity analysis exhibited that reducing load demand by up to 30% decreased LPSP to $0.042\text{x}10^{-4}$, however, LCOE increased by up to 215.2%. Increasing demand by 30% raised LPSP to $7.391\text{x}10^{-4}$, with only a 0.4% rise in LCOE. Diesel prices up to RM 5.00 per liter elevated LCOE to RM 1.2533 per kWh, while LPSP remained unchanged. These results highlight the system's robustness under varying conditions and the need to align system size with demand and manage fuel costs. The findings contribute to the development of robust off-grid systems aligned with the National Energy Transition Roadmap and Sustainable Development Goal 7

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CHAPTER 1
INTRODUCTION

> He is the One Who made the sun a radiant source and the moon a reflected light, with precisely ordained phases, so that you may know the number of years and calculation [of time]. Allah did not create all these except for a purpose. He makes the signs clear for people of knowledge.
> (Qur'an 10:5)

1.1 Research Background

The application of renewable energy (RE) to generate electricity has grown worldwide as a potential substitute for conventional energy sources. This growth is driven by a deep concern about high energy demand due to population growth and industry development, as well as environmental issues caused by fossil fuel-fired power plants [1], [2]. In 2015, the United Nations (UN) launched the 2030 Agenda for Sustainable Development Goals (SDGs), including Goal 7: Affordable and Clean Energy, which calls for access to reliable, sustainable, and modern energy for all. In alignment with this global agenda, Malaysia has integrated RE into its national development plans starting with the 11th Malaysia Plan (2016–2020), followed by the 12th Plan (2021–2025) and 13th Plan (2026-2030), the National Energy Policy, and most recently the National Energy Transition Roadmap (NETR) [3], [4]. These initiatives aim to increase RE's share in the national generation mix to 70% by 2050 [5], [6].

As part of RE generation, photovoltaic (PV) offers a promising mode of electricity generation due to its non-polluting nature, abundance and availability of solar energy resources throughout the year. PV systems have been widely installed in Malaysia via both grid-connected (on-grid) and stand-alone (off-grid) applications [6]. Although the majority of the PV system installations are grid-connected, the stand-alone PV (SAPV) applications serve an important role by supplying electricity in remote areas without grid access. Unlike grid-connected PV systems, which enable uninterrupted power supply due to grid availability as back-up, SAPV systems installations are heavily dependent on energy storage to ensure a regulated power supply while meeting the load demand. The typical energy storage technology ranges from lower-cost lead-acid batteries to higher-cost lithium-ion batteries. However, recent studies postulate the