UNIVERSITI TEKNOLOGI MARA

MULTI- OBJECTIVE OPTIMISATION OF INTERMITTENT LSSPV PLACEMENT FOR GRID STABILITY USING FIPSMA

MASHITAH BINTI MOHD HUSSAIN

Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy
(Electrical Engineering)

Faculty of Electrical Engineering

February 2026

ABSTRACT

Aligned with Malaysia's Twelfth Plan to accelerate renewable energy adoption, this thesis addresses the challenges of integrating high-penetration Large-Scale Solar Photovoltaic (LSSPV) systems into distribution networks which includes intermittency, voltage variability, reverse power flow and increased losses. A two-phase approach is developed to mitigate voltage instability, power loss, and intermittency issues. In Phase 1, the IEEE 39-bus system is embedded with a Western Electricity Coordinating Council (WECC) generic solar model and shunt capacitor compensation to examine system stability under fault conditions. The model demonstrates improved voltage performance and measurable loss reduction. Phase 2 introduces a hybrid optimisation technique, the Fast Iterative Process Slime Mould Algorithm (FIPSMA), formulated using a multi-objective function that incorporates power loss, voltage deviation and voltage stability indices. FIPSMA is tested on three LSSPV capacities (50 MW, 20 MW, and 10 MW) under varying intermittency scenarios based on high-resolution temporal load profiles. The novelty of this study lies in developing a new Typical LSSPV (TYP) profile representing ideal non-fluctuating output and introducing FIPSMA designed to improve convergence stability and overcome limitations found in PSO and GA. Across all scenarios, FIPSMA achieves significant improvement in voltage deviation, consistent reduction in total active and reactive power losses and up to 95% faster convergence compared to PSO and GA. The TYP profile demonstrates a strong correlation ($R^2 = 0.835$) with real operational data. Collectively, the proposed methods establish a robust and scalable framework for optimal LSSPV allocation and grid stability enhancement under uncertain demand and intermittent solar conditions.

ACKNOWLEDGEMENT

First and foremost, I thank God for leading me all the way in this research endeavour by giving me optimum health and surrounding me with generous people who provided assistance. I would like to express my sincere gratitude to my supervisor, Professor Ir. Dr. Zuhaina Hj. Zakaria, who guided and supported me whenever I was lost and in need. I am very fortunate to have her as a research supervisor. I extend my gratitude to my co-supervisors, Professor Dr. Nofri Yenita Dahlan and Professor Dr. Ihsan Mohd Yassin, for their invaluable guidance, support and encouragement throughout this research. I gratefully acknowledge the financial support from the government through the Fundamental Research Grant Scheme (FRGS).

I would like to express appreciation to the utility provider and solar company for granting access to valuable operational data. Their support was instrumental to the success of this research. I am also deeply grateful to industry experts, Mr. Hidzar Radzi, Mr. Salleh, Mr. Musaab, Mr. Azlan and Mr. Ashim for sharing insightful suggestions that guided me toward effective solutions to the industrial challenges addressed in this study.

Finally, I would like to thank my lovely husband, family and friends. Without their love, prayers, special support, patience and understanding, it would be impossible for me to finish this PhD research and thesis journey. It has meant more than words can express.

TABLE OF CONTENT

CHAPTER 1
INTRODUCTION

1.1 Research Background

The accelerating pace of industrial development and population growth has intensified global energy consumption, consequently contributing to the ongoing depletion of fossil fuel resources [1]. Renewable energy sources (RESs), including wind, solar, hydropower, and biofuels, are becoming increasingly important for the energy infrastructure of smart cities, particularly in European cities [2]. These sources are preferable because they produce inexpensive and clean energy and are advantageous for distributed electricity networks [3]. Typically, the distributed generator (DG) uses a wind turbine and a photovoltaic (PV) system. DG is an electric power source that is directly or indirectly connected to the distribution network and can support the increasing demand for smart generation networks [4]. Implementing RESs operations can provide improved efficiency, reduced fossil fuel usage, and low operating and maintenance costs if the RE is installed at the right location and size to maximise its performance [5]. However, choosing an RE with an inappropriate location or size in a specific area may lead to increased losses and operating costs [6]. This work uniquely combines both technical factors (e.g., voltage profile, power losses, and stability) and economic considerations (cost) into the decision-making process through the application of novel algorithms, Fast Iterative Process and Slime Mould Algorithm (FIPSMA) for optimal solar energy connection points.

Among the various alternatives, Large-Scale Solar (LSS) is the most attractive Renewable Energy Source (RES) used worldwide due to its low maintenance costs and ease of installation [7]. Renewable energy combined with traditional energy called a hybrid system has become a popular approach to energy sources because it can lower the operating costs and make the system more reliable [8]. However, a major challenge is developing sustainable energy systems that become efficient and creating optimised models to operate these hybrid energy networks. LSS consists of various photovoltaic (PV) panel plates that convert the sun's heat into electricity depending on the solar irradiation level connected to multiple types of equipment. LSS assigned to the