UNIVERSITI TEKNOLOGI MARA

DAY AHEAD LOAD FORECASTING FOR CAMPUS BUILDINGS WITH SOLAR PV USING A HYBRID CONVOLUTIONAL NEURAL NETWORK AND BIDIRECTIONAL LONG SHORT-TERM MEMORY MODEL

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Thesis submitted in fulfilment
of the requirements for the degree of
Master of Science
(Electrical Engineering)

Faculty of Electrical Engineering

JULY 2025

ABSTRACT

Educational buildings are significant contributors to national energy consumption, with load patterns that fluctuate significantly between semester and non-semester periods, posing challenges for efficient energy management. However, this unique operational structure also presents substantial opportunities for cost savings and income generation. For instance, during semester breaks when energy demand is lower, surplus electricity generated from on-site solar photovoltaic (PV) systems can be exported to the grid, offering potential financial returns. This highlights the importance of accurate load forecasting to support informed energy scheduling and maximize economic benefits. Furthermore, the integration of solar PV introduces additional complexity to energy management due to the inherent variability and intermittency of solar generation. These characteristics require more precise forecasting methods to ensure efficient self-consumption, minimize reliance on the grid, and minimize cost. Therefore, accurate day-ahead load forecasting is essential not only for improving operational efficiency but also for enabling educational institutions to fully capitalize on the economic and sustainability benefits of solar energy. Existing forecasting models often rely on consistent data patterns or necessitate separate models for different periods, which can be inefficient. While various forecasting methods have been explored, including Long Short-Term Memory (LSTM) and Bidirectional LSTM (BiLSTM), research on their application in campus settings remains limited and mostly separating the model into different semester status which is inconvenient for real time application. This study proposes a novel load forecasting approach tailored for both non-semester and semester periods, combining Convolutional Neural Network (CNN) with BiLSTM to improve feature extraction. Three distinct models were developed for validation, namely, Artificial Neural Network (ANN), BiLSTM, and hybrid CNN with BiLSTM (CNN-BiLSTM). The key input features include load consumption, hour of the day, calendar factors (such as holidays), and previous day and week lagged load data. The models were developed using datasets collected at 30-minute intervals over six months from three Universiti Teknologi MARA (UiTM) campuses namely UiTM Permatang Pauh, UiTM Dungun, and UiTM Alor Gajah. Their performance was evaluated using Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Square Error (MSE) and Coefficient of Determination (R^2) on both semester run and combined semester period datasets. The performance evaluation of ANN, BiLSTM, and the proposed CNN-BiLSTM model across UiTM Permatang Pauh, Alor Gajah, and Dungun datasets demonstrates that CNN-BiLSTM consistently outperforms the other models. In the combined dataset, CNN-BiLSTM achieved the highest R^2 values of 0.935, 0.924, and 0.926, surpassing BiLSTM and ANN. Additionally, it achieved the lowest MAPE, reducing errors by up to 26.66% compared to ANN and 5.10% compared to BiLSTM. The combined dataset approach further enhanced model generalization by capturing seasonal variations and transition phases, making CNN-BiLSTM a more robust solution for load forecasting in university campuses.

ACKNOWLEDGEMENT

I extend my heartfelt gratitude to Allah for granting me the opportunity to pursue and successfully complete my Master's degree. I am truly grateful for His blessings throughout this long and challenging journey.

I would like to express my deepest appreciation to my supervisor, Prof. Ir. Dr. Nofri Yenita Dahlan, and my co-supervisor, Assoc. Prof. Ts. Dr. Zuhaila Mat Yasin. Their unwavering support, guidance, and expertise have been invaluable in shaping this research endeavor. I am truly fortunate to have had the opportunity to work under their mentorship.

I am also grateful to the UiTM Facility team for their support in data collection and technical assistance. Their contributions have been instrumental in the successful execution of this research.

I would also like to extend my thanks to my friends who have been by my side throughout this journey. Their assistance and encouragement have been significant sources of motivation.

Finally, I dedicate this thesis to my beloved parents and family members. Their unwavering love, support, and understanding have been the pillars of my strength. This achievement is a testament to their sacrifices and unwavering belief in my abilities. Alhamdulillah, I am forever grateful for their presence in my life.

Once again, I express my deepest gratitude to everyone who has played a part in my academic journey and contributed to the successful completion of this thesis.

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INTRODUCTION

1.1 Research Background

Buildings account for approximately 40% of global energy consumption [1]. It is projected that by 2030, this proportion will escalate to 50%. Malaysia, as a developing country, has experienced a growing demand for energy driven by population growth and expanding economic activities [2]. Nearly 48% of the country's electricity consumption is attributed to buildings [1]. The growing population has driven up energy demands across both residential and commercial buildings, contributing substantially to overall consumption. In Malaysia, more than 100 educational institutions exist, including both public and private universities, as reported by the Ministry of Education [3]. Universities and other academic buildings require substantial energy for daily operations, including lighting, cooling, and electronic equipment. The increasing energy demand in these buildings highlights the need for efficient energy management strategies to ensure sustainability and cost-effectiveness [4].

Malaysia is planning to increase the renewable energy mix by 40% by 2035 [5]. Solar Photovoltaic (PV) systems are among the most suitable renewable energy resources for Malaysia, as they are well-suited to the country's climate. Thus, the implementation of solar PV as energy resource in Malaysia becomes widespread and proper energy management is needed to ensure that the energy is distributed efficiently. Solar PV systems are typically installed on building rooftops, in parking areas, or as ground-mounted systems. The system offers significant advantages by decreasing reliance on coal-powered electricity from the grid. It generates electricity that can be utilized on-site or exported back to the grid, providing users with cost savings [6]. However, merely increasing renewable energy sources without addressing energy consumption is insufficient for ensuring efficient energy use. Achieving effective energy usage requires a balanced approach that combines expanding renewable energy generation with strategies to reduce consumption [7]. This entails promoting energy efficiency programs and implementing smart technologies to optimize energy use. Furthermore, solar PV installations in Malaysia are constrained by maximum demand thresholds, typically around 70% for the Net Energy Metering (NEM) scheme and 85%