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結合衛星雲圖與數值天氣模式之短期太陽能發電預測方法

Short-Term Solar Power Forecasting by Integrating Satellite Cloud Images and Numerical Weather Prediction

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摘要

近年來隨著環保意識提升，再生能源於電網中的占比逐漸增加，其中太陽能發電已被廣泛應用。然而，其輸出易受氣候影響而具高度不確定性，對電力系統運轉造成挑戰。本文提出一種結合衛星雲圖、數值天氣預報與歷史發電量之日內滾動太陽能發電預測方法，以提升短期預測準確度。所提方法依日內雲圖亮度變化將預測時段劃分為兩階段，並考量不同時點天氣預報之不確定性，於各滾動時間訓練相對應模型。此外，採用混合式預測架構，透過多種卷積神經網路萃取影像與數值資料特徵，並以粒子群最佳化演算法調整輸入參數。以容量 500 kWp 之實際太陽能電廠資料驗證結果顯示，所提方法於四季代表月之預測表現皆優於常見時間序列模型，且可隨時間滾動修正預測值，有效提升整體預測準確性。

Abstract

With the increasing penetration of renewable energy driven by environmental sustainability concerns, photovoltaic (PV) generation has become widely deployed in modern power systems. However, PV output is highly sensitive to meteorological conditions and exhibits significant variability and uncertainty, posing operational challenges to grid management.

This study proposes an intra-day rolling forecasting method for short-term PV power generation that integrates satellite cloud images, numerical weather prediction (NWP) data, and historical generation records to improve forecasting accuracy. The proposed approach divides the forecasting horizon into two stages based on intra-day variations in cloud image brightness and accounts for uncertainty in weather forecasts at different time points by training corresponding models at each rolling update interval.

A hybrid forecasting architecture is developed, employing multiple convolutional neural networks (CNNs) to extract features from both image-based and numerical inputs. Particle swarm optimization (PSO) is applied to optimize model input parameters. The proposed method is validated using data from a real-world PV power plant with an installed capacity of 500 kWp. Experimental results show that the proposed approach outperforms conventional time-series models across representative months of all four seasons. Moreover, the rolling forecasting mechanism enables continuous adjustment of prediction outputs, thereby significantly enhancing overall forecasting performance.

關鍵詞(Key Words)：滾動太陽能發電預測(Rolling PV Power Forecasting)、混合預測模型(Hybrid Forecast Model)、卷積神經網路(Convolutional Neural Networks, CNNs)、衛星雲圖(Satellite Cloud Image)、粒子群最佳化(Particle Swarm Optimization, PSO)。

光電變流器構網控制於全黑啟動情境之性能分析與設計方法

Performance Analysis and Control Design of Grid-Forming Photovoltaic Converters under Black Start Conditions

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摘要

隨著全球對再生能源需求的不斷增長，太陽光電(Photovoltaic, PV)系統在電力系統中的滲透率顯著提升，同時對微電網穩定性提出了新的挑戰。本研究聚焦於基於構網型(Grid-Forming, GFM)控制策略的太陽能變流器，探討其在微電網黑啟動及協同電池儲能系統(Battery Energy Storage System, BESS)穩定微電網的性能。通過 MATLAB Simulink 構建包含太陽能系統、電池儲能系統及 GFM 變流器的微電網模型，模擬全黑啟動、負載變化、併網同步及功率調整等多階段情境。研究採用下垂控制(Droop Control)、比例積分(Proportional-Integral, PI)控制、克拉克轉換與帕克轉換及鎖相迴路(Phase-Locked Loops, PLL)等技術，實現電壓、頻率及功率的精確調節。模擬結果表明，GFM 變流器能有效穩定電壓與頻率，特別是在負載突變及 PV 併網時，系統能在合理時間內(如 215 ms 至 522 ms)恢復穩定，電壓振盪保持在 0.96 p.u.至 1.003 p.u.，頻率振盪控制在 59.87 Hz 至 60.07 Hz。本研究驗證了 PV 與 BESS 協同運作下 GFM 控制策略的可行性，為高滲透率再生能源微電網的穩定運行及全黑啟動提供了技術依據，並為未來優化同步控制與功率分配策略奠定了基礎。

Abstract

With the rapid growth in renewable energy deployment worldwide, the penetration of photovoltaic (PV) systems in power systems has increased substantially, posing new challenges to microgrid stability. This study investigates grid-forming (GFM) controlled PV inverters and evaluates their performance under black start conditions and during coordinated operation with battery energy storage systems (BESS) for microgrid stabilization.

A detailed microgrid model incorporating a PV system, BESS, and GFM inverters was developed in MATLAB Simulink to simulate multi-stage operating scenarios, including black start, load variations, grid synchronization, and power adjustment. The control framework integrates droop control, proportional-integral (PI) control, Clarke and Park transformations, and phase-locked loop (PLL) techniques to achieve accurate regulation of voltage, frequency, and power.

Simulation results demonstrate that the GFM inverter effectively maintains voltage and frequency stability, particularly during sudden load changes and PV grid-connection events. The system restores stable operation within 215 ms to 522 ms, with voltage fluctuations confined between 0.96 p.u. and 1.003 p.u., and frequency deviations limited to the range of 59.87 Hz to 60.07 Hz.

The findings validate the feasibility of coordinated PV-BESS operation under a GFM control strategy, providing technical support for stable operation and black start capability in high-penetration renewable microgrids. The proposed design approach also lays a foundation for future optimization of synchronization control and power-sharing strategies.

關鍵詞(Key Words): 構網型變流器(Grid-Forming Inverter)、太陽能系統(Photovoltaic System)、電池儲能系統(Battery Energy Storage System, BESS)、全黑啟動(Black Start)、微電網(Microgrid)、動態穩定性(Dynamic Stability)。

我國《電業法》自由化之回顧與探討—兼論綠電先行 下對公用售電業售電成本及電價之影響

A Review of the Liberalization Framework under the Electricity Act of Taiwan : the Impact of Green-Power-First Policy on the Sales Costs and Electricity Tariffs of the Public Electricity Retailer

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摘要

適逢台電公司 80 周年紀念，本文謹回顧我國《電業法》發展，探討綠電先行對公用售電業之影響。

自《電業法》制定以來，我國供電長年由國營且垂直整合之台電公司承接，至民國 106 年《電業法》推動綠電先行電業自由化，開放設立再生能源發、售電業，使再生能源電力得經轉直供售予用戶。後於 114 年《電業法》再次修正，涵蓋維持台電不分割、開放再生能源售電業互售、納管儲能與需量反應；同時配合《電能轉供及併網型直供營運規章》實施，綠電交易增長快速。

另外，台電公司近年推動多樣綠電商品並不斷進化綠電彈性分配模式，嘗試反應電力供需時間價值，為解決餘電問題開闢新途。

最後，本文兼論自由化下綠電價格影響因素，估至 119 年轉供潛力約 400~450 億度，占整體再生能源發電 4~5 成，並說明台電公司對民營及自有綠電轉供之成本認列作法，分析對電價及電網成本及費率之影響。

Abstract

Commemorating the 80th anniversary of Taipower, this study reviews the evolution of the Electricity Act and examines the impacts of the “green-power-first” policy on public electricity retailing. For decades, Taiwan’s electricity supply was monopolized by the vertically integrated, state-owned Taiwan Power Company. The 2017 amendment initiated market liberalization through a “green-power-first” approach, enabling the establishment of the licensees of renewable-energy-based electricity generating and retailing market participants, allowing renewable electricity to be sold directly to consumers via power wheeling and grid-connected direct supply mechanisms.

The 2025 amendment preserved Taipower’s vertically integrated structure while permitting inter-transactions of renewable-energy-based electricity retailers and incorporating regulatory oversight of grid-connected energy storage systems and demand response. Following the enforcement of the Taiwan Power Company Operating Regulations for Power Wheeling and Grid-connected Direct Supply, green electricity trading has expanded rapidly. Concurrently, Taipower has introduced diverse green electricity products and continuously refined flexible allocation mechanisms to reflect the temporal value of supply and demand, providing new solutions for surplus electricity management.

Finally, this study analyzes the determinants of green electricity pricing under a liberalized market and estimates the potential scale of power wheeling. By 2030, the potential volume of green electricity power wheeling is projected to reach 40-45 TWhs, accounting for approximately 40–50% of total renewable generation. The article also details Taipower’s cost-accounting practices for both self-owned and privately supplied green electricity, and evaluates the resulting impacts on retail electricity prices, grid-related costs and rate structures.

關鍵詞(Key Words)：電業法(The Electricity Act)、電業自由化(Electricity Liberalization)、綠電先行政策(Green-Electricity-First Policy)、公用售電業成本(The Cost of Public Electricity-Retailing Utility)、公用售電業電價(The Rates of the Public Electricity-Retailing Utility)。

未來電網之固態變壓器開發與實用化研究

Prototype Development and Verification of Solid-State Transformers for Future Power Grids

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摘要

本研究探討固態變壓器(Solid-State Transformer, SST)之技術發展趨勢、法規標準，收集整理國內外電網之應用案例，分析比較用於固態變壓器中作為開關元件的各類功率半導體元件材料，並針對一次側為 22.8kV 配電電壓等級，輸出端 380V 三相交流電之固態變壓器進行模擬分析；此外，使用碳化矽元件開發一具額定電壓 1kV、容量 5kVA 之 SST 樣機，並建置一小型展示系統內含能源管理系統、電池儲能、太陽光發電及交/直流負載，以示範驗證 SST 樣機於分散式發電情境下之整合作動及電力品質控制情形。依本研究實證顯示，SST 樣機成功達成因校正、諧波改善、三相負載不平衡修正、不斷電功能、穩壓/穩頻、過流保護、過溫保護、過壓保護，及突波保護之示範驗證。並將階段性成果提出建議。

Abstract

This study examines the technological development trends and regulatory standards of solid-state transformers (SSTs), and reviews domestic and international application cases in power grids. It further analyzes and compares various power semiconductor materials employed as switching components in SSTs. A simulation study is conducted for an SST with a 22.8kV distribution-level primary side and a 380V three-phase AC output. Furthermore, a prototype SST rated at 1kV and 5kVA utilizing silicon carbide components is developed. A small-scale demonstration system is also constructed, incorporating an energy management system, battery energy storage, photovoltaic power generation, and AC/DC loads, to verify the integrated operation of the SST prototype and its power quality control capabilities under a distributed generation scenario. Experimental results demonstrate that the proposed SST prototype successfully achieved power factor correction, harmonic improvement, correction of three-phase load imbalance, uninterrupted power supply, voltage and frequency regulation, as well as overcurrent, overtemperature, overvoltage, and surge protection. Based on these findings, recommendations for future development are provided.

關鍵詞(Key Words)：固態變壓器 (Solid-State Transformer)、電力品質(Power Quality)、寬能隙半導體(Wide Bandgap Semiconductor)。

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計量設備管理系統開發

Development of a Metering Equipment Management System

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摘要

本案旨在為台灣電力公司建置「計量設備管理系統」，進行電度表、PT、CT、MOF、MIU及封印鎖等計量設備之全生命週期管理，涵蓋設備自採購、撥配、裝拆、檢修至報廢等各階段作業。同時整合公司現行之 NCPS、NBS 及 RNIS 系統資料，納入登記單與用戶資料，提升資料的一致性與完整性。另配合現場作業需求，規劃開發行動應用程式，強化人員填報效率與資料正確性，提升現地作業之即時性。

本案依台電既有作業規範盤點各階段工作流程，廣泛蒐集總管理處及 24 區營業處之實務需求，據以建立符合規範的數位化作業流程，進而記錄計量設備生命週期資訊，有效降低管理成本並提升營運效率。

目前系統已完成原型開發並進行多次模擬測試，針對全區部署進行策略規劃、辨識潛在風險並提出因應方案，以確保未來推展至全台區營業處時具備穩定性與實用性。

Abstract

This project aims to develop a Metering Equipment Management System for Taipower, enabling full lifecycle management of metering devices, such as energy meters, potential transformers (PTs), current transformers (CTs), metering outfit facilities (MOFs), meter interface units (MIUs) and security seals. The system encompasses all operational stages, including procurement, allocation, installation and removal, maintenance, and decommissioning. The proposed system integrates data from Taipower's existing systems (NCPS, NBS, and RNIS), and integrates registration forms and customer information to enhance data consistency and integrity. Additionally, in response to on-site operational needs, a mobile application is planned for development to enhance the efficiency and accuracy of personnel data entry, as well as to improve the timeliness of field operations.

To ensure alignment with existing operational practices, this project systematically reviews Taipower's standard procedures and maps workflows across all lifecycle stages. Practical requirements were extensively collected from the headquarters and 24 regional service offices, based on which standardized and regulation-compliant digital workflows were established. The system enables comprehensive recording and tracking of lifecycle information for metering equipment, thereby reducing management costs and improving operational efficiency.

A prototype system has been developed and validated through multiple simulation tests. Furthermore, a deployment strategy for system-wide implementation has been formulated, including the identification of potential risks and corresponding mitigation measures, to ensure system stability and practicality for future rollout across all regional service offices.

關鍵詞(Key Words)：計量設備管理系統 (Metering Equipment Management System)、電度表 (Electricity Meter)、生命週期(Life Cycle)、計量設備(Metering Equipment)、數位化管理(Digitization Management)。

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電力變壓器油中氣體分析之機器學習故障診斷方法比較

Comparison of Machine Learning-Based Fault Diagnosis Methods for Dissolved Gas Analysis in Power Transformers

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摘要

變壓器油中氣體分析為診斷油浸式變壓器內部故障之關鍵技術。傳統的診斷方法如杜瓦三角形與杜瓦五邊形雖直觀有效，但其診斷精度與自動化能力有限。近年來，機器學習演算法已成為提升油中氣體分析診斷準確性與效率之新興工具。本文旨在綜論變壓器故障診斷之演進，從傳統的杜瓦幾何方法，到現代應用支援向量機、決策樹、卷積神經網路以及新興的柯爾莫哥洛夫-阿諾夫網路等智慧演算法。文中將闡述各方法之原理與應用，並探討如何使用混淆矩陣客觀評估模型性能。此外，本文亦將說明 Python 程式語言如何整合上述技術，成為實現油中氣體分析智慧化診斷之強大平台，為變壓器之預測性維護提供一套完整之解決方案。

Abstract

Dissolved Gas Analysis (DGA) is a key technology for diagnosing internal faults in oil-immersed transformers. Traditional diagnostic methods, such as the Duval Triangle and Duval Pentagon, are intuitive and widely used. However, they are limited in diagnostic accuracy and automation capability. In recent years, machine learning algorithms have emerged as effective tools for improving the accuracy and efficiency of DGA-based fault diagnosis. This paper reviews the evolution of transformer fault diagnosis methods, ranging from conventional Duval geometry methods to modern intelligent algorithms, such as Support Vector Machine (SVM), Decision Tree, Convolutional Neural Network (CNN), and the emerging Kolmogorov-Arnold Network (KAN). The principles and applications of these methods are discussed, and confusion matrices are employed to provide an objective evaluation of model performance. Furthermore, this study demonstrates how the Python programming environment can be utilized to integrate these techniques into a unified framework for intelligent DGA-based diagnosis, thereby providing a comprehensive solution for predictive maintenance of power transformers.

關鍵詞 (Key Words)：油中氣體分析 (Dissolved Gas Analysis, DGA)、變壓器故障診斷 (Transformer Fault Diagnosis)、支援向量機 (Support Vector Machine, SVM)、決策樹 (Decision Tree)、卷積神經網路 (Convolutional Neural Network, CNN)、柯爾莫哥洛夫-阿諾夫網路 (Kolmogorov-Arnold Networks, KAN)。

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LED 照明燈具能效及規格蒐集分析

Energy Efficiency and Specifications Analysis of LED Lighting Products

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摘要

本研究針對全球主要國家 LED 照明燈具商品之能效現況與標示內容進行蒐集與比較分析，並探討電氣特性與資訊揭露間的關聯性。研究涵蓋歐盟、中國、日本、印度等國際市場共 13 家主要廠商，蒐集 5,384 筆樣本；國內部分則包含 39 家廠商、60 款燈具型號，共 6,300 筆標示資料。分類結果顯示，國內以 LED 筒燈/嵌燈為市場主力，國外則以 LED 平板燈樣本數最多。發光效率分析結果指出，國內 LED 路燈效率最高達 207.2 lm/W，具高功率照明技術優勢；LED 筒燈/嵌燈發光效率整體亦高於國外，反映應用成熟度。整體而言，燈具如天井燈和平板燈在國內外皆維持高效率表現，惟部分類型仍呈效能離散，顯示產品品質尚有提升空間。此外，國內具調光/調色功能產品占比約 14.10%，顯示智慧照明應用已逐步展現發展潛力。

Abstract

This study systematically collects and comparatively analyzes the energy efficiency status and labeling information of LED lighting products across major global markets, and further examines the relationship between electrical characteristics and information disclosure. It covers 13 major manufacturers across international markets, including the European Union, China, Japan, and India, totaling 5,384 samples. The domestic dataset comprises 39 manufacturers and 60 lighting fixture models, with 6,300 labeled data entries.

The classification results show that LED downlights and recessed luminaires dominate the domestic market, while LED panel lights represent the largest share in international samples. Luminous efficacy analysis indicates that domestic LED streetlights achieve a maximum efficiency of 207.2 lm/W, demonstrating a technological advantage in high-power lighting applications. In addition, domestic LED downlights and recessed luminaires exhibit higher overall luminous efficacy than their international counterparts, reflecting a higher level of application maturity. Overall, luminaires such as high-bay lights and panel lights maintain high efficiency in both domestic and international markets. However, certain categories exhibit notable performance dispersion, suggesting room for improvement in product quality. Additionally, approximately 14.10% of domestic products are equipped with dimming and color-tuning functions, suggesting a growing potential for smart lighting applications.

關鍵詞(Key Words)：LED 照明燈具(LED Luminaires)、效率(Efficiency)、智慧照明(Smart Lighting)。