Modelling The Microgrid Application In Datacentre Challenges Towards the Sustainability

Abstract:

As datacentres seek sustainable energy solutions without directly investing in power infrastructure, this paper introduces a predictive model designed to assist third-party energy providers in estimating the benefits of microgrid integration under Power Purchase Agreements (PPAs) or similar contracts. By optimizing microgrid configurations tailored to green datacentres, the model evaluates Distributed Energy Resources (DERs) and storage solutions to project cost efficiencies, operational resilience, and greenhouse gas reductions. This framework equips energy providers with a robust tool for assessing and communicating the anticipated savings and sustainability gains achievable through microgrid solutions, facilitating strategic planning aligned with industry standards and regulatory demands.

1. Introduction:

In the digital age, datacentres are pivotal infrastructures, hosting servers, virtual machines, and vast data storage solutions that businesses rent to stay ahead. As of 2023, these technological powerhouses consume a significant share of the world's electricity—approximately 3%. This consumption rate has remained stable but is poised for growth, with projections indicating an increase to 4% by 2030 due to an expansion in technology use and a surge in digitalization across various sectors, according to Datacentres magazine.

Traditionally, datacentres depend on the main power grid, predominantly fuelled by fossil energies. However, the global IT sector's exponential growth is driving an unprecedented increase in data traffic and energy demands. This surge not only escalates operational costs but also amplifies greenhouse gas emissions. A promising solution to mitigate these impacts involves integrating renewable energy-based microgrids, which offer a sustainable alternative to conventional power sources.

Microgrid systems, particularly beneficial for datacentres, enhance power generation efficiency, bolster reliability, reduce transmission losses, and curb pollution. The advent of green datacentres marks a significant evolution towards a sustainable industry. By minimizing environmental footprints, cutting costs, adhering to stringent regulations, boosting brand reputation, and paving the way for a sustainable future, green datacentres present immense benefits. They stand as a testament to the synergy between ecological responsibility and economic sensibility. Discussions on microgrid design primarily focus on two critical aspects necessary for a robust architecture: component sizing and configuration.

These elements are essential in crafting an effective, efficient, and environmentally friendly energy solution for the datacentres of tomorrow.
These components are vital for devising an efficient, effective, and eco-friendly energy solution tailored for the datacentres of the future. The process begins with microgrid component sizing, which involves selecting components strategically to reduce both capital and operational expenses while also taking environmental considerations into account.

The choice of Distributed Energy Resources (DERs), energy storage systems, and additional components must meet the rigorous demands dictated by power loads, IT requirements, budgetary constraints, maintenance needs, climatic data, and utility tariffs. Moreover, the inherently variable nature of renewable energy sources, coupled with fluctuations in load demand due to human behaviour, necessitates a flexible and adaptive microgrid design approach.

Operational planning within the microgrid framework seeks to optimize performance in the short to medium term. This strategy aims to minimize costs and effectively manage uncertainties, load variations, and unexpected disruptions.

The criteria for selecting renewable energy sources, along with the factors that influence energy generation and storage, are pivotal in shaping the sustainability strategies of datacentres. This paper outlines the methodologies used to select these sources and evaluate their impacts. Datacentres typically leverage Special Energy Contracts or Power Purchase Agreements (PPAs) to secure renewable energy. This approach allows them to manage Scope 2 emissions—those related to purchased electricity—without the need for direct investment in power generation infrastructure. Microgrids play an essential role in this strategy by enabling more flexible and efficient integration of renewable energy sources, supporting datacentres in their efforts to reduce their carbon footprint while adhering to financial and regulatory imperatives.

This white paper delves into the architectural considerations necessary for the seamless integration of microgrids in datacentres. We address the essential elements of microgrid design, focusing on component selection—key to optimizing both the economic and environmental impacts of a facility. We discuss how distributed energy resources (DERs), energy storage systems, and other necessary components are selected to meet the diverse demands imposed by technological needs, operational costs, climatic conditions, and regulatory frameworks.

In this section, we explore the energy consumption patterns and major load parameters of data centres, focusing on how they manage their energy demands to align with sustainability goals:

- **Green Datacentres Load Demand:** Green datacentres prioritize sustainability from design to operation. They are constructed using low-emission materials and incorporate sustainable features like environmentally friendly landscaping and renewable energy technologies such as solar photovoltaics and wind turbines. These datacentres are engineered for optimal energy efficiency and minimal environmental impact. Furthermore, green datacentres employ microgrids that participate in demand response programs, effectively managing power and communication systems to allow the integration of renewable energy into the main grid.
- **Information Technology Equipment (ITE):** The core of a datacentres is its Information Technology Equipment, primarily made up of server farms and their power supply systems, responsible for about half of the datacentre’s total energy consumption. The primary power for these servers comes directly from the main power source. In the setup, alongside

the servers, are power distribution units (PDUs) which distribute this main power throughout the server farm. Uninterruptible Power Supplies (UPS) are also integral, providing backup power that ensures continuous operation during main power failures until generators can take over. Datacentres typically organize their servers and storage units into racks within the server farm. The number of racks can vary widely depending on the scale and purpose of the facility, reflecting the diverse nature of data centres in terms of size and capacity.

- **Cooling System:** The cooling system is the second-largest consumer of power in a data centres. Its main role is to dissipate the heat generated by the servers. Most systems utilize a water chiller plant that operates on either vapor-compression or absorption cycles to cool the transport fluid. The efficiency of the cooling process and the power consumption of the chiller plant are heavily influenced by the ambient temperature, and various techniques are employed to optimize the heat transfer from the datacentres to the cooling system.
- **Miscellaneous Power Consumption:** Other components such as lighting, security devices, control and monitoring systems, and networking facilities fall into the category of miscellaneous power consumption. This category, which constitutes approximately 6% of the total power usage, is not dependent on server utilization or environmental conditions but rather on the size of the datacentres itself.

These components together define the energy framework of a datacentre, highlighting the critical areas where energy management and sustainability practices can be implemented to reduce overall power consumption and carbon footprint.

When selecting distributed energy resources (DER) for a microgrid, several factors must be considered, including the type and priority of the load, the average energy demand, and the available DER technologies. The optimal size of the DER is determined by various factors such as capital investment, installation, operation and maintenance costs, power capacity, system reliability, greenhouse gas emissions, and the expected lifespan of the microgrid.

It's important to note that while the cost-benefit of microgrids powered by renewable energy is often assessed by comparing the cost of energy produced by the DER units to the cost of purchasing the same amount of energy from the main grid, affordability is not the only goal. Environmental sustainability and energy security are equally important considerations in the design of a DER-based microgrid system.

In this white paper, the renewable energy sources considered will include photovoltaics and wind energy, paired with a battery system for energy storage.

I. The power generation of photovoltaic (PV) panels mainly depends on the solar irradiation which can be obtained from below equation: (1)

$$PPV = \left(\frac{H}{100}\right) \times \left(P_{max} + \mu_{P_{Max}}(T_{amb} + \mathrm{H}\ \frac{NOCT - 20}{800} - 25\right)$$

Where is:

- PPV is the predicted power output of the PV module.
- H is the solar irradiance on the PV module surface (in W/m²).
- P_{max} is the maximum power output of the PV module under standard test conditions (STC) (in watts).
- $\mu_{P_{Max}}$ is the temperature coefficient of power
- T_{amb} is the ambient temperature (in °C).
- $NOCT$ is the nominal operating cell temperature (in °C).

II. In energy management systems, the mathematical model of the battery encompasses key parameters such as the state of charge (SOC) and the charging/discharging rate (C-rate). The relationship between charge/discharge time and the C-rate varies depending on the battery type, but generally, a higher C-rate enables faster charging and discharging of energy. However, frequent use of a high C-rate can shorten the battery's lifespan and reduce its overall efficiency. When it comes to SOC, specific guidelines are essential for optimizing battery performance and preventing damage. Maintaining a SOC above 20% ensures the system can bridge energy gaps during times when renewable energy generation is insufficient to meet load demand. On the other hand, charging the battery beyond 80% SOC should be avoided, as it can lead to physical damage and degrade the storage system's performance. The energy storage system plays a vital role in improving the stability and efficiency of microgrids. It helps lower peak generation demands while also balancing generation with consumption patterns, ensuring a dynamic adjustment of power supply. This balancing act is crucial for optimizing resource utilization and preserving the overall integrity of the system. For further details, refer to Cummins' battery storage system.

To appropriately size a battery for energy storage, the following equation is typically used: (2) Battery Capacity (kWh) = (Load Demand (kW) × Autonomy (hours)) / Depth of Discharge (%)

Where:

- Load Demand is the average power required
- Autonomy is the number of hours the battery is expected to provide energy.
- Depth of Discharge (DoD) is the allowable percentage of battery depletion (e.g., 80% DoD).

This equation helps ensure that the battery is sized correctly to meet the energy needs of the system while maintaining optimal performance.

2. Microgrid Enhancement Model:

This section presents the mathematical frameworks used to model both the costs and greenhouse gas emissions inherent to the components of a microgrid system. The primary objective is to optimize the sizing of renewable energy generation units and energy storage systems by simulating hourly electricity flows, related costs, and emissions. This method allows for a detailed evaluation of various microgrid configurations to identify those that deliver the best environmental and economic outcomes.

Enhancement Criteria: Each microgrid configuration is evaluated by calculating the total hourly operational costs, combined with a present-value assessment of capital and lifetime expenses, while also quantifying greenhouse gas emissions. These factors are incorporated into a fitness function that determines the cost-effectiveness and environmental impact of each potential configuration. This approach ensures that all configurations are assessed **holistically, balancing both financial and sustainability goals.**

Calculation of Outputs: For each possible microgrid setup, the power output from various renewable generation units—such as photovoltaic (PV) systems, wind turbines, biomass generators, and hydroelectric systems—is calculated based on real-time local environmental conditions. These conditions include factors such as solar irradiance for PV systems, wind speeds for turbines, available organic material for biomass generators, and water flow rates for hydroelectric power. Additionally, load demands are dynamically evaluated to align with the specific environmental and operational conditions of the site. This comprehensive assessment ensures that each configuration is tailored to optimize the unique characteristics of the microgrid's location, taking advantage of all viable renewable resources.

Enhancement Objective: The goal of this enhancement process is to identify the microgrid configuration that achieves the lowest annual fitness value. This value reflects the optimal balance between cost and greenhouse gas emissions, ensuring both economic efficiency and environmental sustainability. This is particularly important for green datacentres, where operational costs and emissions reduction are equally critical in achieving sustainability targets.

Implementation Details: This structured approach provides a clear methodology for improving microgrid designs, specifically aimed at enhancing the efficiency and sustainability of green datacentres. By assessing the financial and environmental impacts of different configurations, the model supports strategic objectives focused on emissions reduction and resource optimization within these crucial infrastructures.

3. Generation and Storage Costs:

Renewable Energy Generation (Photovoltaic, Wind, Biomass, and Hydropower): The annual costs for renewable energy generation units, such as photovoltaic (PV) systems, wind turbines, biomass generators, and hydropower systems, are composed of two main elements. The first is a fixed annual cost, covering capital investment, installation, and operational expenses, including maintenance. The second element is the potential revenue from selling excess energy back to the utility grid through a feed-in tariff. This tariff varies depending on the utility company and the type of renewable energy system in use, with different rates applying to solar, wind, biomass, or hydropower technologies.

3.1: The annual cost of a renewable energy generation unit $C_{an}[g]$
can be expressed as: (3) (4)

$$C_{an}[g] = C_{an}^{fix}[g] - \sum_{h=1}^{8760} P_g[h] \times \mathcal{R}_g$$

Where:

- $C_{an}^{fix}[g]$ is the fixed annual cost for the generation unit.
- $P_g[h]$ represents the power sold to the utility company at hour h.
- $\mathcal{R}_g$ is the feed-in tariff rate for the renewable energy.

- where $P_g[h]$is the power sold to the utility company at h hour from g renewable energy generation unit, here assuming a year (8760 h).

3.2: Battery Storage System:

The annual cost of a battery storage system includes a fixed annual cost that covers the investment and installation costs, and a degradation cost, which accounts for the reduction in battery performance due to charge and discharge cycles. The annual cost of the battery system C_{an}^{bat} calculated as follows (4)

$$C_{an}^{bat} = C_{an}^{fix.bat} + \sum_{h=1}^{8760} P_{bat}[h] \times D$$

Where:

$C_{an}^{fix.bat}$represents the fixed annual cost of the battery system.

$P_{bat}[h]$ denotes the power charged or discharged at hour h

D is the degradation rate.

3.3: Total Generation and Storage Costs:

The total annual cost of the renewable energy generation and storage systems is the sum of the individual annual costs for each renewable energy generation unit and the battery system, expressed as: (4)

$$C_{an}^{total} = \sum_{g}^{NRE} C_{an}[g] + C_{an}^{bat}$$

Where *NRE* refers to the total number of renewable energy generation units. This equation provides a comprehensive view of the total cost of the energy generation and storage infrastructure over a year.

3.4: Grid Electricity Costs:

Electricity purchased from the utility grid is represented by a cost function that reflects the utility's tariff structure. The annual cost of purchasing electricity from the grid is determined using the following equation: (4)

$$C_{an}^{grid} = \sum_{h=1}^{8760} f_{grid}\left(P_{grid}\lceil h \rceil\right)$$

Where:

$f_{grid}\left(P_{grid}\lceil h \rceil\right)$ is the cost function for grid electricity at hour h

$P_{grid}\lceil h \rceil$ is the power purchased from the grid during hour h in KW

3.5: Emissions Costs:

In addition to financial costs, the environmental impact of energy consumption must be considered. Renewable energy systems such as PV, wind, and battery storage are typically emission-free. However, electricity purchased from the grid may produce emissions, depending on the energy mix used by the utility (e.g., coal, natural gas, nuclear). The total annual emissions associated with grid electricity consumption are calculated as (5)

$$\mathrm{E}_{an} = \sum_{h=1}^{8760} P_{grid}\lceil h \rceil \times \sum_{p=1}^{\mathrm{M}} X_p$$

Where

$P_{grid}\lceil h \rceil$ is the power purchased from the grid during hour h

M is the number of pollutants considered.

X_p is the emission factor for each pollutant (e.g., Carbon Dioxide, Nitrogen Oxides)

Microgrid Power Balance and Reliability

In the context of microgrid systems, especially those servicing green datacentres, reliability is crucially defined by the system's ability to maintain a continuous power supply under varying conditions. Two primary reliability concerns in microgrid operations are Loss of Power Supply (LPS) and Loss of Load (LOL). These factors are essential for assessing the robustness and resilience of a microgrid. (6)

Understanding LPS and LOL:

- Loss of Power Supply (LPS) :occurs when there is a failure or deficiency in the power generation sources within the microgrid. This could be due to equipment failure, reduced renewable energy output (due to weather conditions affecting solar or wind power), or any interruption in the primary power supply.
- Loss of Load (LOL) happens when the microgrid is unable to meet the electricity demand of the connected loads. This might be due to an unexpected increase in load or insufficient generation capacity.

Power Dynamics in Green Data Centres:

Primary power sources in green data centres typically include solar P_{tot-pv} and wind power P_{tot_wt} with total demand denoted as P_{GDC} (4)

- **Under generation Scenario** ($P_{GDC} > P_{tot\_PV} + P_{tot\_wt}$) Deficits are covered by:
  - Battery storage (P_{bat}) Provides power during shortfalls.
  - Grid power (P_{grid})Supplements power when renewable sources are inadequate.
- Overgeneration Scenario ($P_{tot\_pv} + P_{tot\_wt} \ > \ P_{GDC}$
  - Charging batteries: Surplus power charges the batteries.
  - Exporting to the grid: Excess energy can be sold back to the grid.

Power Balance Equation:

The microgrid must satisfy the following balance to ensure operational reliability:(7)

$$P_{tot\_PV} + P_{tot\_WT} + P_{grid} = P_{GDC} + P_{bat}$$

This equation asserts that the total power from renewable sources, supplemented by the grid, when necessary, matches the datacentre's demand and battery charging needs.

Strategies for Enhancing Reliability:

- **Capacity Planning**: Proper sizing of renewable sources and batteries based on predictive analytics.
- **Advanced Forecasting**: Utilizing weather and load forecasts to anticipate energy needs.
- **Grid Interconnections**: Leveraging grid connections to manage power surpluses or shortages effectively.

Overall, balancing power supply with demand in microgrids is crucial for the uninterrupted operation of green data centres, emphasizing the importance of strategic planning and advanced management systems

Conclusion:

In this paper, we have presented an optimization model for designing microgrid configurations tailored to the unique energy demands of green datacentres. As datacentres increasingly recognize the value of integrating renewable energy, their motivations may vary—whether driven by financial incentives, regulatory requirements, environmental goals, or regional power limitations. The proposed model offers a versatile solution, accommodating various trade-offs between cost efficiency, sustainability, and reliability. By providing a mathematical framework, this tool enables third-party energy providers to strategically optimize microgrid designs, meeting both the economic and environmental objectives of datacentres. This approach supports the industry's broader shift towards sustainable energy solutions, equipping providers and operators with actionable insights to navigate the evolving landscape of green energy in datacentre operations.

Reference:

(1) Dunlop, J. P. (2012). *Photovoltaic systems* (3rd ed.). American Technical Publishers.

(2) *Redway Power. (2024, September 15).* How to calculate usable battery capacity based on depth of discharge (DoD). *Redway Power. https://www.redwaypower.com/how-to-calculate-usable-battery-capacity-based-on-depth-of-discharge-dod/*

(3) Mizani, S., & Yazdani, A. (2009). Optimal design and operation of a grid-connected microgrid. In 2009 IEEE Electrical Power & Energy Conference (EPEC) (pp. 1–6). IEEE. https://doi.org/10.1109/EPEC.2009.5420925

(4) Rahmani, R., Moser, I., & Cricenti, A. L. (2020). Modelling and optimisation of microgrid configuration for green data centres: A metaheuristic approach. Future Generation Computer Systems, 108*, 742–750. https://doi.org/10.1016/j.future.2020.03.013*

(5) S. Mizani, A. Yazdani, Optimal design and operation of a grid-connected microgrid, in: Electrical Power & Energy Conference (EPEC), 2009 IEEE, IEEE, 2009, pp. 1–6.

(6) T. Logenthiran, D. Srinivasan, Optimal selection and sizing of distributed energy resources for distributed power systems, J. Renew. Sustain. Energy 4 (2012) 053119.

(7) Ghanaee, R., & Foroud, A. A. (2019). Enhanced structure and optimal capacity sizing method for turbo-expander based microgrid with simultaneous recovery of cooling and electrical energy. *Energy*, *170*, 284–304.

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