Outlook

Revised manuscript (Paper ID number: KUUB2024 - 00161)

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2 attachments (3 MB)
KUUB-2024_Jordan_Revised_Final.docx; KUUB-2024_Jordan_Revised_Final.pdf;

Dear organizing committee of the Postgraduate Research Colloquium,

I have attached the revised version of the accepted manuscript in Word and PDF files. Please note that registration with payment has been completed.

I would like to mention that considering the scope of the paper and the page limit, the response to the minor reviewer's comment was addressed in the conclusion section.

Kind Regards,
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27 November 2024

Dear Jordan

Thank you for submitting a manuscript to 1st Konsortium Universiti Universitas Borneo (KUUB) Postgraduate by Research Colloquium 2024 to be held in Miri, Sarawak, Malaysia from 3 – 5 December 2024.

Re:Energy Storage Management of Green Hydrogen-Integrated Microgrid

Paper ID number: KUUB2024 - 00161

We are pleased to inform you that your manuscript has been accepted for an oral presentation. For your perusal, the reviewers' reports are also enclosed. Your abstract will be included in our book of abstract and your manuscript will be published in our conference proceeding. Therefore, please do make necessary amendments (if there are any from the reviewers), and get back to us with the revised manuscript by 29 November 2024.

Please note that if you have not done so, one of the authors is required to register by **29 November 2024.** Please refer to the registration details available at https://gradschool.curtin.edu.my/postgraduate-by-research-colloquium-2024/.

On behalf of the 1st Konsortium Universiti Universitas Borneo (KUUB) Postgraduate by Research Colloquium 2024 Organising Committee, we would like to thank you for your active participation in our conference and look forward to seeing you in Miri.

Warmest regards,

Professor Agus Saptoro
Organising Committee Chairman

Energy Storage Management of Green Hydrogen-Integrated Microgrid

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Abstract. The increasing integration of renewable energy sources (RES) within microgrids presents significant challenges for energy storage and grid stability. As the world moves towards sustainable energy solutions, effective energy resource management becomes crucial. This study develops a robust modelling approach for a hybrid microgrid system that uses hydrogen storage to manage energy fluctuations. The main goal is to assess how well this integrated model balances supply and demand while maintaining frequency and voltage stability under different operational conditions. In this model, hydrogen storage is combined with renewable energy resources, and droop control serves as the conventional method to maintain system performance. The model performance has been evaluated under various load conditions, disconnection events, and fault scenarios. The findings reveal that the hybrid microgrid system maintains stable frequency within the ±5% limit but the case for the voltage is different, as it drops below the 15% limit in grid-connected and off-grid mode. The implications of using hydrogen storage in combination with renewable energy resources are significant for future energy policy development. This study suggests that policymakers should consider hydrogen a critical component in energy storage solutions, enhancing grid resilience and flexibility. It promotes energy security and supports the transition to low-carbon energy systems, ultimately paving the way for a more sustainable energy landscape.

1. Introduction

Integrating renewable energy resources within modern power systems has brought numerous benefits, such as reduced carbon emissions and a transition towards sustainable energy solutions. However, the intermittent and unpredictable nature of these resources presents substantial challenges, particularly in terms of maintaining grid stability and ensuring the reliability of energy supply. Microgrids, which enable localized energy generation and distribution, offer a promising framework to incorporate RES efficiently. Yet, the fluctuating nature of renewable energy can lead to instability, especially with frequency and voltage regulation, necessitating the development of advanced energy storage solutions [1]. Among the various storage technologies being explored to support the power grid, hydrogen storage has gained increasing attention. This is due to its potential to provide large-scale, long-term energy storage [2]. Hydrogen can be produced using excess renewable energy through electrolysis and stored for later use, offering a flexible and scalable solution to address energy fluctuations. The integration of hydrogen storage within microgrids could help balance supply and demand while simultaneously enhancing frequency and voltage stability, particularly in systems with high-RES penetration [3]. The potential of hydrogen storage to enhance grid stability has been supported by various studies. For instance, in [2], the author highlights how hydrogen can serve as an energy carrier, facilitating the transition towards a more resilient energy system by enabling long-duration storage. Apart from that, [3] discusses the role of hydrogen storage in improving frequency and voltage control in microgrid applications, showcasing its capacity to mitigate fluctuations in renewable generation. The research study presented in [4] further underscores the synergy between hydrogen storage and other renewable technologies, illustrating how this integration can enhance overall system reliability and performance. Building on the insights from previous studies [2] – [8], this study aims to address a significant research gap concerning green hydrogen energy management. The study developed a robust model for a hybrid microgrid system incorporating hydrogen storage as a key element for managing energy fluctuations. By combining traditional control methods with innovative storage technologies, the research evaluates the system's performance under various operating conditions, including load injection and disconnection events and fault conditions. It seeks to demonstrate the effectiveness of hydrogen storage in improving the reliability and resilience of microgrids.

2. Green hydrogen-based microgrid

The integrated modelling of the hydrogen production unit (HPU) in Figure 1 aims to sustain the balance of active power flow as given in (1) [5]. In this equation, P_{MG} is the total generated power at the microgrid; P_{PV} represents the solar PV power; P_{FC} denotes the fuel cell power; $P_{LD,LS}$ is the load demoing including the power loss. The system modelling and control strategy including the main components of a microgrid are outlined in the following subsections.

$$P_{MG} = (P_{PV} + P_{FC}) - P_{LD,LS} \tag{1}$$

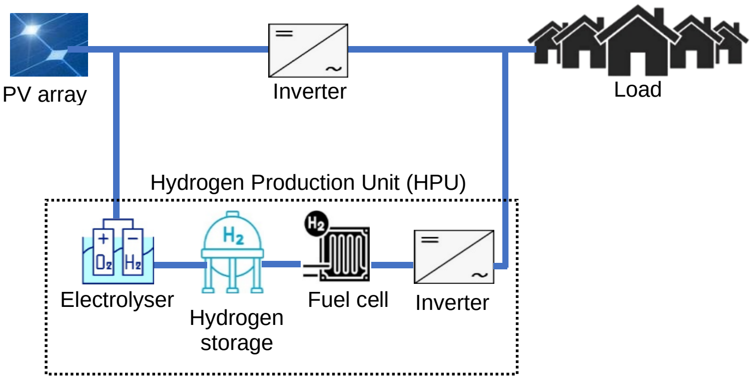

Figure 1: Renewable hydrogen microgrid

2.1. System modelling

The microgrid's modelling scheme involves renewable resources, AC with DC loads, and HPU. Referring to Figure 1, the microgrid is powered by the solar PV array, and the surplus energy generated from PV is converted into hydrogen that can be compressed and stored in tanks. The PV array in the system is modelled using (2). In this equation, the temperature de-rating factor "Y_{PV}" represents the rated power of the solar PV system in kW; f_{PV} is a de-rating factor that accounts for the efficiency of the PV system; G denotes the solar insolation under actual conditions (kW/m²), while G_{stc} represents the solar insolation at standard testing conditions; α_{PV} refers to the PV module's temperature coefficient (%/°C); T_c is the PV cell temperature under actual conditions; $T_{c,stc}$ is the cell temperature at standard test conditions [6].

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G}{G_{stc}}\right) \left(1 + \alpha_{PV}(T_c - T_{c,stc}\right) \tag{2}$$

The electrolyzer converts electrical energy into chemical energy by splitting water into hydrogen and oxygen. The standard equation for an electrolyzer defines the relationship between input current and hydrogen production which is grounded in Faraday's law of electrolysis. According to this law, the amount of substance produced at an electrode is proportional to the electric charge passed through the system, in this sense, the hydrogen production rate is expressed in (3) [7]. In this equation, F represents the Faraday constant, whereas n_F, n_{ele}, and I_{ele} refer to Faraday efficiency, the number of electrolytic cells connected in series, and the output current of the electrolytic cell, respectively; z denotes the number of electrons required per molecule of hydrogen gas "H_2" typically "2".

$$v_{H2} = \left(\frac{n_F n_{ele} I_{ele}}{zF}\right) \tag{3}$$

Hydrogen storage is a critical aspect of energy systems that rely on hydrogen as a fuel, especially when integrated with RES. Green hydrogen storage allows for the buffering of energy produced from intermittent renewable sources, ensuring that energy is available when needed. The amount of hydrogen stored is given by (4) in which $\boldsymbol{P_h}$ represents the actual tank pressure (P_a), while $\boldsymbol{P_{hi}}$ is the initial hydrogen pressure in the bottle. In the second part of equation (4), $\boldsymbol{K}$ is a proportionality constant that accounts for system-specific factors, such as efficiency or design constraints. At the same time, $\boldsymbol{R}$ is the universal gas constant, approximately 8.314 J/ (mol K). Additionally, $\boldsymbol{T_s}$ and $\boldsymbol{V_s}$ represent the bottle's temperature (K) and volume (m^3), respectively. The hydrogen flow rate "N_{H2} (kg/s)", the molar mass of hydrogen "M_{H2} (kg/mol)", and the molar volume $\boldsymbol{V_m}$ (m^3/mol), are also important factors in determining the amount of hydrogen stored [8].

$$P_h - P_{hi} = K\frac{T_S N_{H2} R}{V_S M_{H2}};\ \{K = \frac{P_h V_m}{R T_S} \tag{4}$$

The proton-exchange membrane (PEM) fuel cell is a reversed counterpart of the electrolyzer. It converts hydrogen and oxygen into electricity, with water and heat as by-products. The output PEM fuel cell is modelled using (5). In this equation, P_{fc}, E_{fc}, I, and N are the power produced by the fuel cell, voltage across the fuel cell, current flowing through the fuel cell, and number of fuel cell stacks respectively [9].

$$P_{fc} = E_{fc} \cdot I \cdot N \tag{5}$$

2.2. *Droop control*

Droop control is a decentralized method where each generator or inverter adjusts its output based on local measurements, ensuring proportional load sharing [10]. The term "droop" refers to the deliberate reduction in frequency or voltage as the load increases. This mimics the natural behavior of synchronous generators, where increased load causes a slight drop in frequency or voltage. They can effectively share the load by giving each power source similar droop characteristics. In this study, two types of droop control are implemented for the renewable hydrogen microgrid (Figure 1). Inspired by studies presented in [10] and [11], the block diagrams of frequency droop control and voltage droop control are structured in Figure 2.

Frequency droop control relates active power "P" to system frequency "f", as active power demand increases, the frequency decreases linearly based on active power droop coefficient "k_p". The difference between the operating frequency and the nominal frequency "f_0" is expressed in (6), where "P_0" is the reference active power. In this formula, the droop coefficient for active power determines how much the frequency will drop per unit increase in the active power.

$$f = f_0 - k_p(P - P_0) \tag{6}$$

Voltage droop control establishes a relationship between reactive power "Q" and voltage "V", as reactive power demand increases, the voltage decreases linearly. This can be expressed in (7), where Q_0 is the reference reactive power output, "V_0" is the nominal voltage, and "k_Q" is the droop coefficient for reactive power, determining how much the voltage will drop per unit increase in reactive power.

$$V = V_0 - k_Q(Q - Q_0) \tag{7}$$

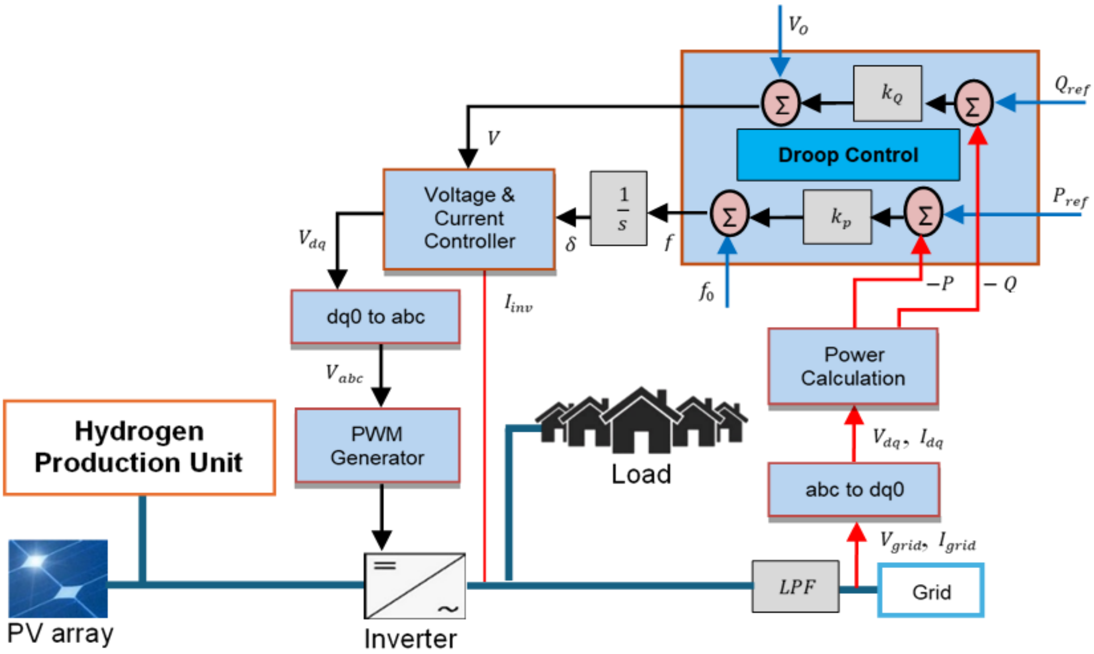

Figure 2: Droop control structure for renewable hydrogen microgrid

3. Results and Discussion

A Simulink model in MATLAB was redesigned [8] for a standard microgrid test system (Figure 2) to evaluate the effectiveness of HPU in controlling frequency and voltage fluctuations. The system's behavior has been assessed under different scenarios such as load injection, disconnection, and fault conditions in both islanded and grid-connected modes. These scenarios were performed under optimal conditions with solar irradiance of 1000 W/m^2 and ambient temperature of 25°C. The main findings are discussed in the following paragraphs.

Figures 3 and 4 show the system response during load injection and disconnection with grid-connected and islanded modes. In the islanded mode and without hydrogen storage, a significant voltage drop occurred as seen in Figure 3 (a, b). The voltage fluctuation is notable, even when the hydrogen energy storage was utilized (Figure 3 (b)). This indicates that droop control is not ineffective in maintaining stable voltage during system disturbance. It is to be noticed that the voltage stability has been maintained in the grid-connected mode and with hydrogen storage as depicted in Figure 3 (a). While the droop control was not performing well during voltage fluctuation, it is worth mentioning that frequency stability is enhanced when using droop control as seen in Figure 4 (a, b).

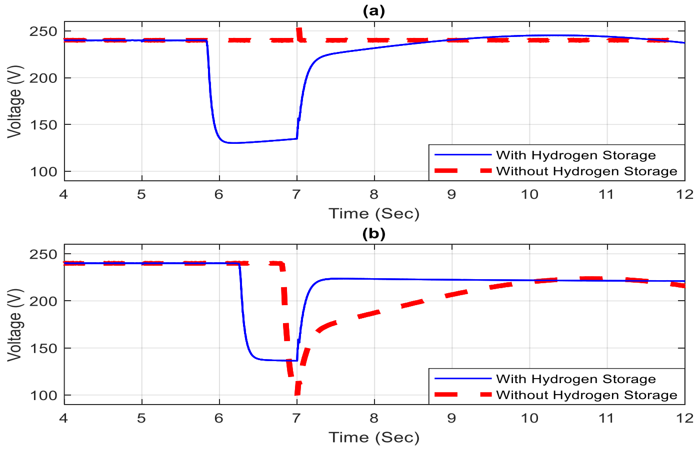

Figure 3: Voltage during load Injection and disconnection (a) Grid-connected; (b) Off-grid

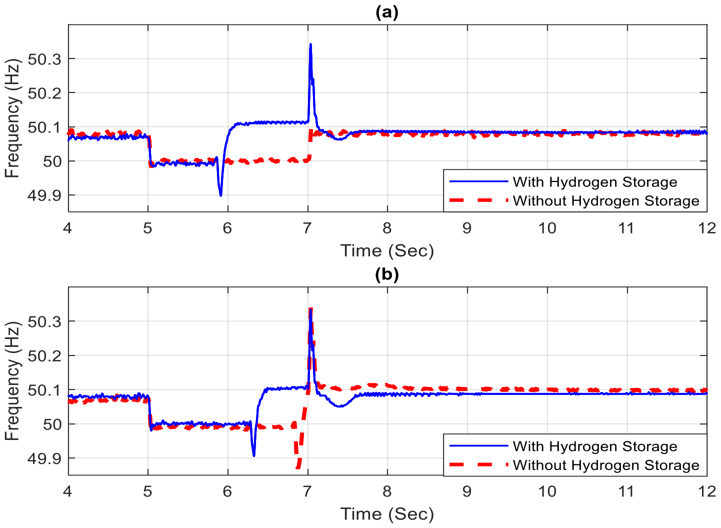

Figure 4: Frequency during load injection and disconnection (a) Grid-connected; (b) Off-grid

Figures 5 and 6 show the results of fault scenarios that applied to the system, at t = 3-Sec one-phase to ground, t =6-Sec two-phase to ground, and at t = 9-Sec three-phase to ground. As seen in these figures, when hydrogen storage is connected, the overshoots of voltage and frequency can be reduced. The fault scenarios pushed both parameters to critical levels, indicating instability. In all cases, the frequency has been maintained within the ±5% range, but voltage dropped below the allowable limit of 13% [12]. This is due to the poor droop control performance even though the power source is sufficient.

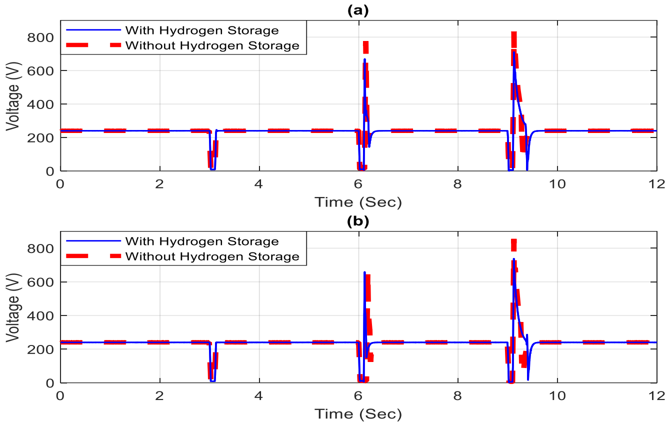

Figure 5: Voltage during fault conditions (a) Grid-connected; (b) Off-grid

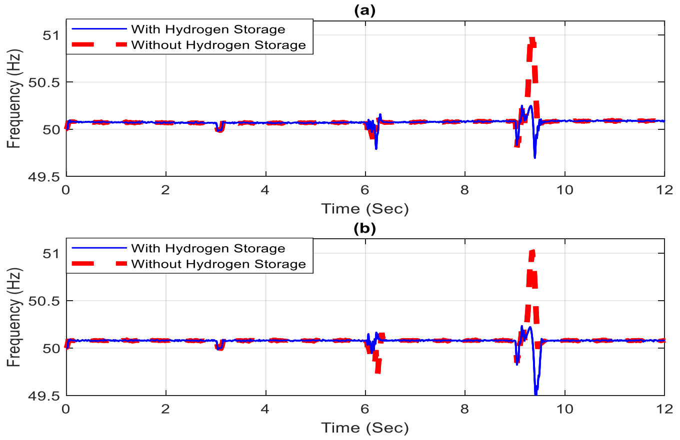

Figure 6: Frequency during fault conditions (a) Grid-connected; (b) Off-grid

4. Conclusion

This study highlights the crucial role of hydrogen energy storage in maintaining frequency and voltage stability in a microgrid, both in off-grid and grid-connected modes. In off-grid mode, green hydrogen-based microgrid helped smooth out significant frequency fluctuations caused by load injections, and fault conditions. In contrast, in grid-connected mode, it reduced the microgrid's dependence on the grid and improved autonomy. The findings confirm that hydrogen storage can enhance grid reliability, especially in systems with high renewable penetration. Future research will focus on developing a robust control approach that will be benchmarked with other existing control strategies to address uncertainty scenarios, such as unpredictable renewable generation. Further, the control indicators for performance assessments will be considered including integral time absolute error and integral square error, to ensure the system can handle various challenges while maintaining grid stability and resilience.

Acknowledgements

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