Grid Stabilizing Frequency Detector

Eric M. Doolin, Aymes Glidewell, Alex Cruz, and Briggs Green

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract*— Escalating electricity demands, renewable energy integration, and aging infrastructure increase the need for grid stability. This proof of concept introduces the Grid Stabilizing Frequency Detector (GSFD), leveraging household water heaters to dynamically adjust operations in response to grid fluctuations. Employing a Frequency Detector, it initiates a shutdown or startup sequence. Key features include an informative display and response mechanisms. While stochastic elements are not fully demonstrated in this first iteration, real-time data monitoring validates GSFD's efficacy. Compatibility beyond Grid Interactive Water Heaters extends its impact, offering a cost-effective solution for grid stabilization. Ultimately, this design presents a promising avenue for grid reliability enhancement and potential consumer incentives.**

***Index Terms*—Demand response, frequency regulation, stochastic controller, water heaters.**

I. Introduction

This project represents a significant advancement in smart grid technology, aimed at enhancing grid stability by intelligently managing the power consumption of household water heaters in response to grid frequency fluctuations. The system is based on a research paper developed by Dr. Guanyu Tian and Dr. Qun Zhou Sun, which utilizes an advanced stochastic control algorithm to address the challenges of grid stability, particularly with the increasing integration of renewable energy sources, where demand-side regulation is a viable method to compensate for stress on the grid. Although the original research paper proposed a stochastic control algorithm, this project serves as a proof of concept and does not implement the stochastic element due to the complexities of testing. As such, a frequency deadband will be implemented for testing and demonstration purposes, while the method and hardware to implement the stochastic decision-making processes will be included in this project.

The system continually monitors the signal between the load center and the load, extracting information such as signal frequency, source voltage, and load current-draw in the form of analog signals. These signals are then conditioned and filtered, digitized through analog-to-digital converters, processed through the microcontroller, and output to the LCD. After acquisition, the frequency data is then used to control the power supply going to the load.

II. Safety Standards

OSHA's Electrical Safety Codes, particularly regulations like 1915.181(c) and 1910.335(a)(1)(ii), are crucial for safety. These codes mandate the proper de-energization of circuits and the rigorous maintenance of protective equipment, which is critical for ensuring the safety and reliability of the project's electrical components. These codes are relevant to our project because this device must work with two 120v lines a 30A breaker.

III. System Overview

As mentioned before, this design is engineered to enhance power grid stability through active engagement of household water heaters. This system interfaces with the power grid and dynamically adjusts water heater operations in response to real-time frequency measurements. This design employs a precision Frequency Detector that initiates shutdown or startup sequences to modulate the load accordingly, thereby supporting grid stabilization efforts.

A. Measurement and Control Processes

The system's measurement process starts with the conversion of the grid's AC signal into a DC pulse signal suitable for analysis by a microcontroller. This involves a multi-step process including rectification, signal conditioning, and zero-crossing detection. The microcontroller then interprets these digital signals to obtain the grid's frequency in real time.

In the event of frequency deviations falling below the predetermined deadband to signify grid stress, the system is designed to intervene by cutting power to the load. This response triggers a control mechanism with a reaction time of approximately 10 milliseconds, providing almost immediate stabilization support. This design decision aligns with the guidance received that over-frequency scenarios, which indicate excess power in the grid, can typically be resolved on the supply side. Therefore, our system's focus is on addressing under-frequency conditions, which are more challenging to manage and can signal a need for urgent demand-side response measures.

B. Prospective Enhancements

While the research conducted provides a blueprint for a local stochastic control algorithm able to manage grid stability through demand-side regulation, the current iteration of the system does not incorporate these stochastic elements. This is not due to hardware limitations, as the algorithm doesn’t require specific components, but rather a very specific set of computational instructions and conditions that were unable to be tested within the project's scope.

The design, however, is intentionally structured to facilitate future integration of the stochastic algorithm. When realized, this advanced control strategy is anticipated to enhance the precision of the system's load adjustments in response to grid conditions. It will allow for a more dynamic and finely tuned demand-side management approach, contributing to grid stabilization without the need for additional componentry. This leaves room for significant potential advancements in how residential power consumption can aid in the broader context of smart grid management.

C. Broader Implications

This design's potential extends beyond the management of water heater loads. The underlying technology showcases a scalable approach to demand response that can be applied to a wider array of household and commercial appliances. The implications for grid stability, particularly in regions heavily reliant on intermittent renewable energy sources, are significant. By providing a decentralized mechanism to balance the supply-demand relationship, the system presents a pathway toward more sustainable and reliable power systems.

IV. Software Design

A. Stochastic Control

In the September 2023 issue of IEEE Transactions on Smart Grid, a significant study titled "A Stochastic Controller for Primary Frequency Regulation Using ON/OFF Demand Side Resources" by Guanyu Tian and Qun Zhou Sun was featured. This research underscores the potential of leveraging residential ON/OFF devices like heaters and coolers to aid in the frequency regulation of the power grid. The study highlights different control strategies, including centralized, distributed, and local methods, each with its own set of challenges, such as the high costs associated with establishing communication systems for centralized and distributed controls, and the lack of device coordination in local controls.

To address these challenges, a novel approach utilizing a local stochastic controller that can dynamically adjust the power response without the need for direct communication between devices is proposed. This controller uses a stochastic filter to randomize the on/off actions of devices based on the current grid frequency, effectively contributing to grid stability. The practicality and efficiency of this stochastic control method were validated through simulations involving grid-interactive water heaters under various stress conditions, demonstrating its potential in real-world applications.

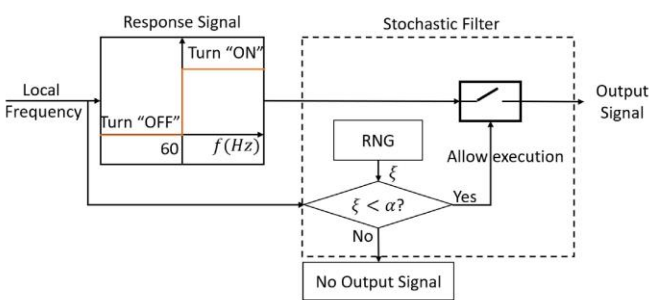


Fig. 1. Design of the S-DSM controller for ON/OFF devices.

The core of the stochastic controller comprises a logic component and a stochastic filter, working in tandem to monitor and respond to deviations from the nominal grid frequency. This innovative approach eliminates the need for a frequency dead band, enhancing system frequency convergence. The study's mathematical modeling and simulations present a promising outlook for the stochastic controller's application in frequency regulation, particularly emphasizing its adaptability and precision in maintaining grid stability. This research lays the groundwork for future developments in demand-side management, presenting a scalable and cost-effective solution for enhancing the resilience and efficiency of power grids.

By implementing the stochastic algorithm across a virtualized network of 1800, 2100, and 2800 grid interactive water heaters, the research demonstrated that the system is not only scalable but also effective at achieving nominal grid frequency convergence. The simulation for 1800 water heaters showcases the algorithm's base-level efficiency, where even a relatively small number of devices contributes to grid stability. Increasing the pool to 2100 water heaters reflects an improved convergence rate, indicating that the controller's effectiveness scales with the number of devices. The most substantial impact is observed in the simulation with 2800 water heaters, where the rapid convergence towards the nominal frequency

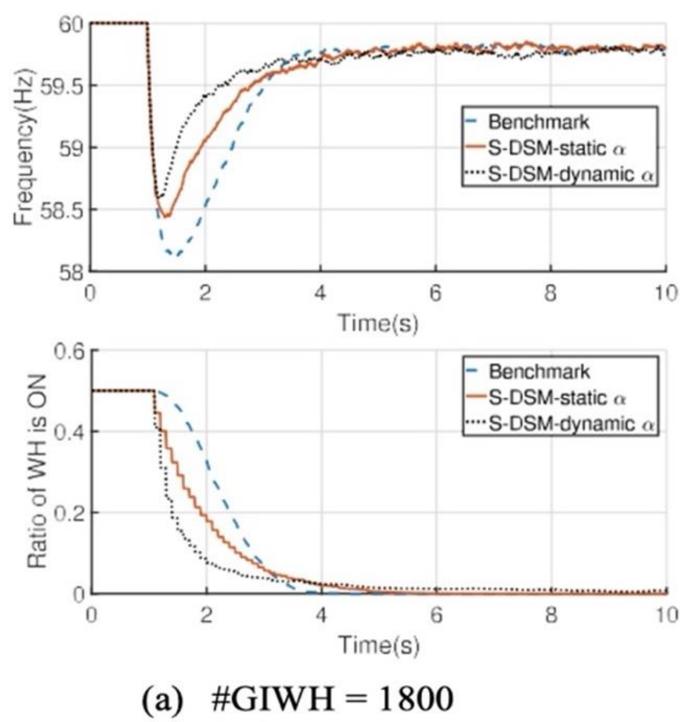


Fig. 2. Proof of Grid Convergence on multiple GIWH simulations (a)

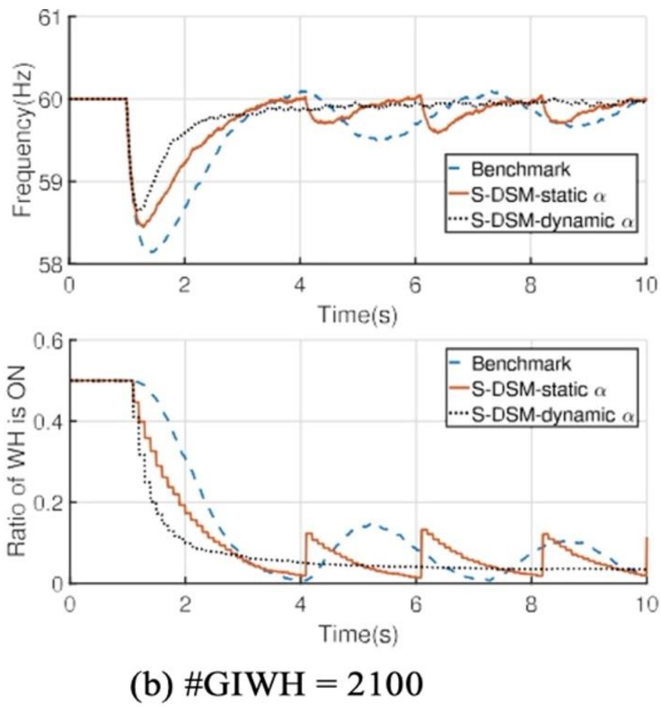


Fig. 3. Proof of Grid Convergence on multiple GIWH simulations (b)

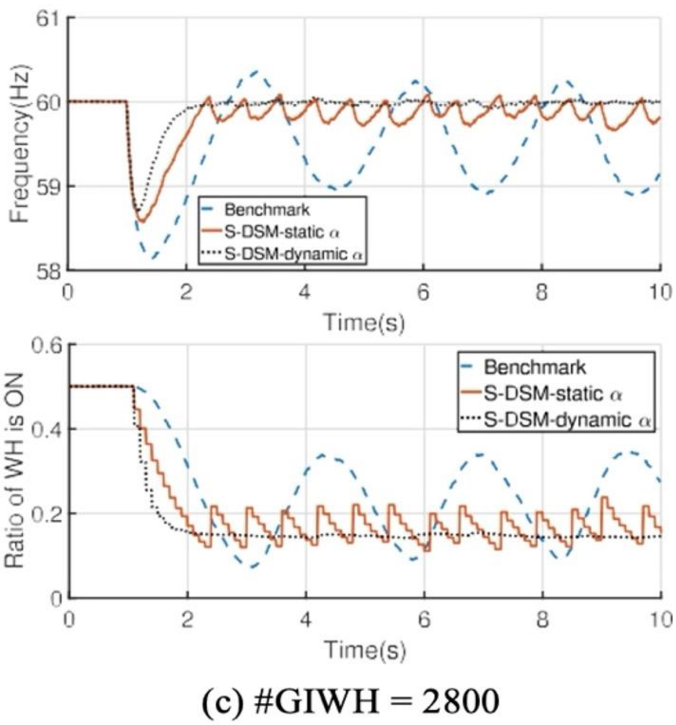


Fig. 4. Proof of Grid Convergence on multiple GIWH simulations (c)

illustrates the potential for this technology to manage larger-scale operations.

These simulations confirm the stochastic controller's foundational principle: as the number of controlled devices increases, the overall system stability enhances, showing a directly proportional relationship between scale and efficiency. The outcomes indicate a path forward, where the deployment of such controllers in households and businesses could significantly bolster grid resilience. These results serve as a proof of concept for policymakers and stakeholders in the energy sector, illustrating a practical, cost-efficient method for advancing the stability and sustainability of the power grid.

B. Code Flowchart

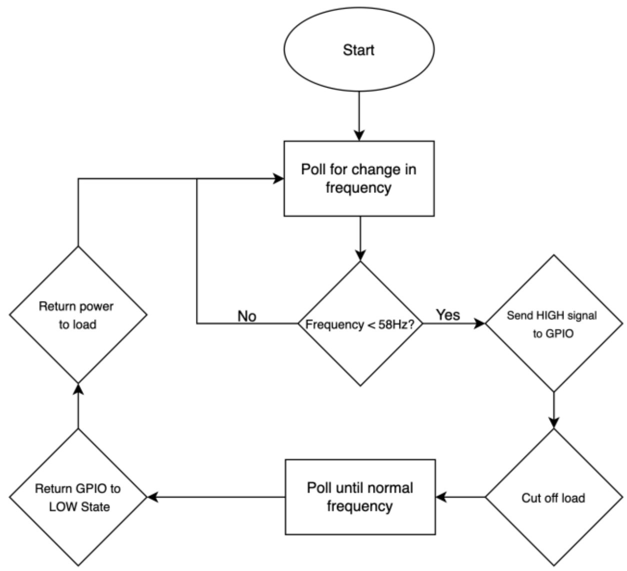


Fig. 5: Software Flow Chart

The system utilizes a continuous polling mechanism to monitor the frequency of the incoming power supply. When the microcontroller detects a frequency dip below the threshold of 58 Hz, it immediately asserts a high signal on a designated GPIO pin. This high signal serves as an indicator of the abnormal frequency condition and persists until the system frequency returns to its normal operating range. Once the frequency stabilizes within the acceptable limits, the microcontroller changes the GPIO signal, switching it to a low state. This approach ensures that the system can quickly respond to frequency deviations and provide a reliable means of signaling the current power supply status to other connected components or subsystems.

While this method provides a reliable means of detecting and signaling frequency deviations, future iterations of the product could benefit from adapting a stochastic algorithm. This algorithmic enhancement would enable more sophisticated decision-making and control strategies that would aid the grid much more than this system currently does.

To validate the effectiveness of the stochastic algorithm, Hardware-in-the-Loop (HIL) testing could be employed. HIL testing allows for the integration of the physical system with a simulated environment, enabling comprehensive validation of the algorithm's performance under various scenarios. However, due to the complexity of setting up the HIL communication infrastructure and the associated testing environment, this approach was not implemented in the current design. Nevertheless, the nature of the system architecture allows for possible future integration of HIL testing, providing a pathway for accurate validation and refinement of the stochastic algorithm. By leveraging HIL testing in future iterations, the product can be thoroughly evaluated and optimized, ensuring reliability in real-world applications.

V. System Components

A. *MSP430F5529*

The system is controlled by the MSP430F5529 ultra-low-power microcontroller, which is part of the MSP430 family. This microcontroller is equipped with a 16-bit RISC CPU, which can operate at speeds up to 25 MHz. It is sufficient for accurate real-time frequency measurements and control tasks. The MSP430F5529 also provides a variety of built-in features, including 12-bit analog-to-digital converters (ADCs), timers, and multiple communication options, making it a good fit for managing the system's requirements while maintaining low power consumption. The device will be utilizing the MSP430F5529 in conjunction with the ESP32-WROOM-32D using UART pins, TX and RX, in order to display important information on the display.

B. *ESP32D*

While the ESP32 is a highly capable microcontroller that is used in many IoT(Internet of Things) applications, it will be used simply to drive the TFT LCD that has been chosen. The ESP32-WROOM-32D is a compact and highly versatile microcontroller module that will have the very simple purpose of controlling the functions of the screen. The ESP32 offers exceptional performance and connectivity options that enables communication with another microcontroller as well as a wide range of peripherals and sensors. Communication will happen using UART to receive data from the MSP430F5529 and displaying it to the LCD through SPI. The ESP32 will be using the TFT_eSPI library which is a popular Arduino library specifically designed for driving TFT LCD displays with ease. This library simplifies the process of driving TFT displays, enabling the creation of engaging graphical interfaces.

C. *LCD*

This design features a 3.5-inch TFT touchscreen LCD, which serves as a user-friendly interface displaying a variety of real-time measurements and system statuses. With a resolution of 480x320 pixels, the screen shows a dynamic graph tracking the grid frequency over time and other critical metrics such as current, voltage, and the count of the system's interactions with the water heater load. This eliminates the need for physical buttons, providing a sleek and efficient means of user interaction. The display is connected to the microcontroller through a serial peripheral interface (SPI), facilitating the rapid update and responsiveness necessary for monitoring the system's performance. The LCD will also be able to turn on/off with the use of a toggle switch so the screen won't stay on constantly.

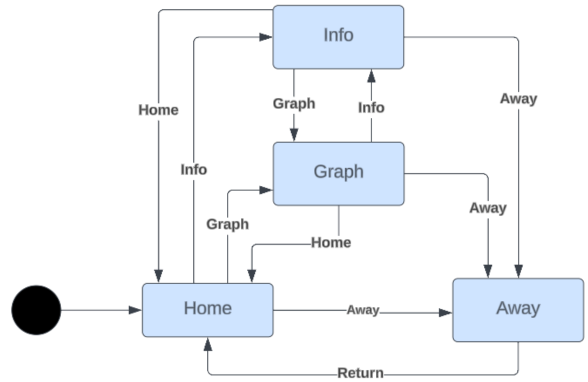


Fig. 6. State Diagram

The user will be able to interact with the screen as it is a touch screen and will be able to navigate through a menu of different pages which will be on the left side of the screen. Whenever the user selects a page they would like to navigate to, that tab will be highlighted. Shown in Fig.4 above, there will essentially be four different pages. The 'Home' page, 'Info' page, 'Graph' page, and finally the 'Away' page.

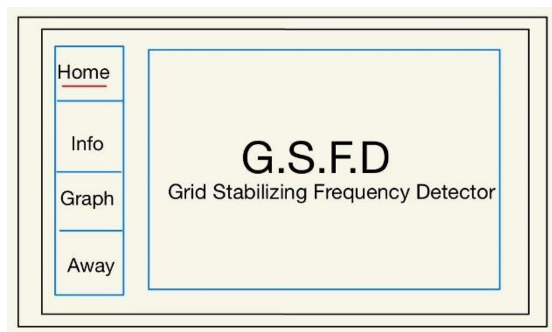


Fig. 7. Illustrative View of the 'Home' screen of the TFT LCD.

Upon the very first startup, the 'Home' screen will be displayed and will serve as a landing page for the user. The name of our project, GSFD (Grid Stabilizing Frequency Detector), will be shown as well as the pages menu to the left as shown in Fig.5. From this page, the user will be able to navigate to any of the other pages they would like to explore.

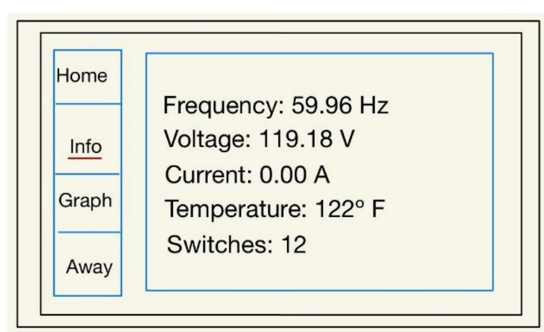


Fig. 8. Illustrative View of the 'Info' screen of the TFT LCD showing critical metrics.

The 'Info' page will do exactly what its title says… it will display important information that has been obtained by our system such as frequency, voltage, current, temperature, and switches, which means the amount of times the GSFD has switched off the load due to the frequency deviating from the nominal value.

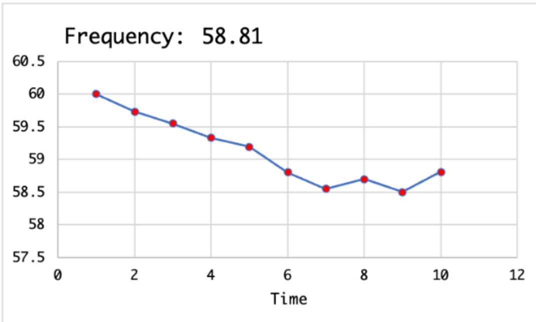


Fig. 9. Illustrative View on TFT LCD Screen Showing Real-Time Grid Frequency and Temporal Frequency Trend.

Next, the user will be able to navigate over to the 'Graph' page. This page will show a real-time grid frequency and temporal frequency graph as seen in Fig.7. This graph will show the changes in frequency over time as well as the current frequency value at the top of the graph so the user won't have to decipher what exact value the most recent point is plotted to on the y-axis.

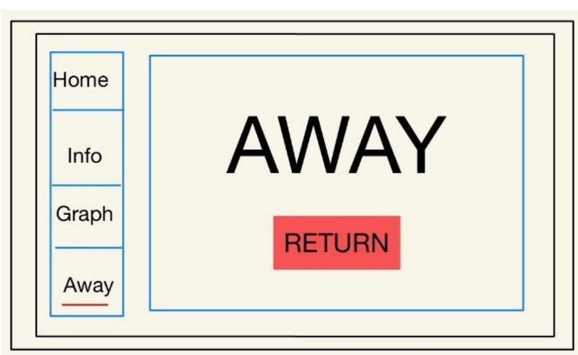


Fig. 10. Illustrative View of the 'Away' screen of the TFT LCD.

The final page is the 'Away' page. This comes from one of our stretch goals which was to implement some sort of vacation mode. The purpose of this page is for the user to access it if they want our system to keep their water heater turned off indefinitely, but still turn it on periodically only so their water won't go completely cold. While on this screen, we would want to disable the functions of all other buttons on the screen except for the RETURN button as seen in Fig.8. Our reasoning behind the decision to disable every other button is based on the fact that there would be no need to display any information or interact with buttons if the water heater is off. Once the RETURN button is pressed, all normal functionalities will be resumed, and the display will navigate back to the 'Home' page.

D. ADC

In the research, various analog-to-digital converters (ADCs) were explored to find the right fit for the design, focusing on converting analog voltage signals representing grid frequency into digital values for microcontroller processing. Initially, the design revolved around using an external ADC due to the potential for increased responsiveness and accuracy. SAR ADCs were considered for their satisfactory speed-resolution balance and power efficiency, and Sigma-Delta ADCs for their high resolution and superior noise performance.

However, upon further evaluation, it was determined that the onboard 12-bit ADC included in the MSP430F5529 microcontroller provided sufficient readings for the application. The built-in ADC offered an adequate balance between conversion speed and resolution, while also simplifying the overall design and reducing the number of external components required. By leveraging the microcontroller's integrated ADC, the development process and the complexity of the design were minimized with little impact on the functionality of the device, maintaining its full operational capabilities.

Although the current design utilizes the onboard ADC, future iterations of the GSFD may benefit from employing an external ADC, depending on the specific requirements and constraints of the application. The nature of the design allows for the integration of alternative ADC solutions, such as the previously considered ADS131A04 Sigma-Delta ADC from Texas Instruments, should the need for higher resolution or improved noise performance arise. This flexibility ensures that the system can be adapted to meet the evolving demands of grid frequency stabilization, while maintaining a focus on precision, reliability, and efficient implementation.

E. Current Transformer

The Amgis CT-1030 solid-core current transformer provides a linear voltage output for a pass-through current in the range of zero to thirty amps RMS. This component was chosen as its maximum current rating matches the thirty-amp circuit breakers found in most residential electric water heater configurations

F. Solid State Relay

The system uses a normally closed (NC) high-current solid-state relay (SSR) to control the power supply to the water heater, selected because of its rapid response time which is needed for immediate grid correction. While relays are most commonly available in normally open (NO) configurations, this SSR is in a normally closed (NC) state, meaning the water heater remains powered on until a signal exceeding 3v from the microcontroller's GPIO pin is applied. This action causes the SSR to open, turning off power to the water heater to quickly reduce the grid load as needed. The SSR's rating of 30A at 120v AC ensures safe and reliable operation within the system.

G. *Circuit Protection*

To safeguard the master PCB, a dedicated step-down PCB has been implemented that efficiently converts the secondary side of the 12vAC transformer to a stable 5vDC signal. The deliberate separation of the step-down functionality onto a distinct board is a strategic measure to isolate high voltages and currents from the master PCB, thereby ensuring the integrity of its intricate measurement circuits. By doing so, the risk of signal interference or cross-coupling is minimized, which could otherwise compromise the accuracy and reliability of the system's performance.

During the testing phases of the project, numerous unexpected challenges arose, notably the recurrent issue of the launchpad board sustaining damage. Further investigation revealed a minor leakage current originating from the Current Transformer, which traveled back up the control line to the Microcontroller. To address this, a MOSFET, specifically the A03400 model, was introduced into the design. This MOSFET effectively acts as a buffer between the MSP and the relay, mitigating the leakage current problem and ensuring the integrity of the test board during subsequent evaluations.

VI. Demonstratable Specifications

The specifications for this device ensure its precision and reliability for measuring and reacting to grid frequency fluctuations. With frequency detection featuring 1% resolution and 1% accuracy, the system guarantees precise monitoring of grid frequency. The voltage measurement capabilities, with 5% resolution and 5% accuracy, offer a balance for monitoring the voltage level, which should consistently hover near 120VAC for our demonstration, given the product will be using wall power. However, it is important to note that many conventional electric water heaters run on 240v with two 120v lines supplying power to the two heating elements.

The load interaction counter operates at a 95% working rate, indicating robust performance in real-time conditions, Furthermore, the control mechanism's response time of less than 1 second underscores the system's quick adaptability to changes, ideal for automated processes and energy management where swift reactions are vital such as the case with GSFD. These specifications underscore the system's role as a dependable tool in monitoring and reacting to grid frequency fluctuations. It should be noted that he actual response time of the hardware is much faster at around 11ms, but for demonstration purposes, a 1s response time was chosen as the bare-minimum specification for ease of proof. The 1s specification is adequate for this project as well as grid stability.

VII. Data Acquisition

A. *Frequency Measurement*

To measure the grid frequency accurately, a circuit with an NPN bipolar junction transistor (BJT) configured as a zero-crossing detector was designed, along with a bridge rectifier and filter. This configuration detects when the AC voltage signal crosses the threshold voltage (approximately 0.6v) for the NPN BJT to turn on. When this happens, the bridge rectifier outputs a pulse. This pulse is then sent to the microcontroller's analog-to-digital converter (ADC) for sampling and frequency calculation. The design ensures that the microcontroller receives a clear rising-edge signal for precise frequency measurements, while also safely managing the 120v AC input.

Fig. 11. Oscilloscope input of 12vAC line (yellow) and output of Frequency circuit (green)

B. *Voltage Measurement*

To measure the supply voltage, this device converts the 12VAC signal coming from the secondary side of the step-down transformer, rectifies it through a full-wave diode bridge rectifier, conditions the signal using a filtering capacitor, and reduces the amplitude using a voltage divider made from a series resistor and the input impedance of the ADC. This signal is then processed through to the MCU where it is evaluated and then scaled back up to represent the 120VAC supply signal on the primary side of the transformer

C. *Current Measurement*

To measure the current draw of the load, as well as the current draw of all internal circuitry of this device, a solid-core current transformer is used on the neutral line running between the load center and the water heater. This line was chosen as most electric storage water heaters are comprised of two heating elements, with a total potential difference of 240VAC. Since this device will only interrupt one of the two 120VAC lines going to the load, utilizing the “hot” line would only represent some of the current draw from the load. By utilizing the neutral line, this device captures the return current from both 120VAC lines as it returns to the load center. The current transformer outputs a linear voltage signal that is scaled down by a factor of ten, which is then passed to the PCB, where the signal is then rectified through a full-wave operational amplifier precision rectifier, buffered, and then sent to the ADC for digitization. Op-amps were used for this circuit to prevent tradition diode voltage drops to ensure measurability of lower-amplitude current signals. As the current transformer outputs a voltage 1/10th of the input current, any current under 7 amps RMS would output a voltage under 0.7 volts RMS, which is the average turn-on voltage of many general-purpose diodes found in diode rectifiers.

D. *Temperature Measurement*

The design incorporates a temperature sensor closely coupled to the hot water line of the water heater which allows for an accurate estimation of the tank's internal water temperature. The external placement on the outlet line provides a practical method for users to monitor the heating system's performance. Temperature data acquisition is executed via a MAX31865 RTD-to-Digital Converter. This converter interfaces directly with an ESP32 Development Board, which processes the sensor readings. The system delivers temperature readings to consumers through the lcd display, ensuring they have access to the correct information for managing their water heating system.

VIII. POWER SUPPLY AND POWER DISTRIBUTION

The system's design is structured to accommodate different components, each requiring specific voltage levels. The setup includes a 120vAC to 12vAC step-down transformer that feeds the 5vDC power supply and both the frequency and voltage measurement circuits. The 5vDC power supply rectifies the incoming sinusoidal input where the signal is then filtered and fed into an LM7805 voltage regulator, which supplies a constant 5vDC supply to the MSP430 MCU, ESP32, LCD, LM3940 3.3vDC regulator, ICL7660A -5vDC inverter, and all active components on the PCB. The 3.3vDC from the LM3940 supplies power to several pins on the MSP430 MCU, LCD via a backlight toggle switch, the MAX31865 temperature module and a constant 3.3vDC signal to one side of the SSR control. The -5vDC from the ICL7660A supplies the -5v rail on the two LM062 operational amplifiers. The voltage and frequency measurement circuits both rectify and filter the 12vAC signal to generate voltage outputs that are fed into the ADC.

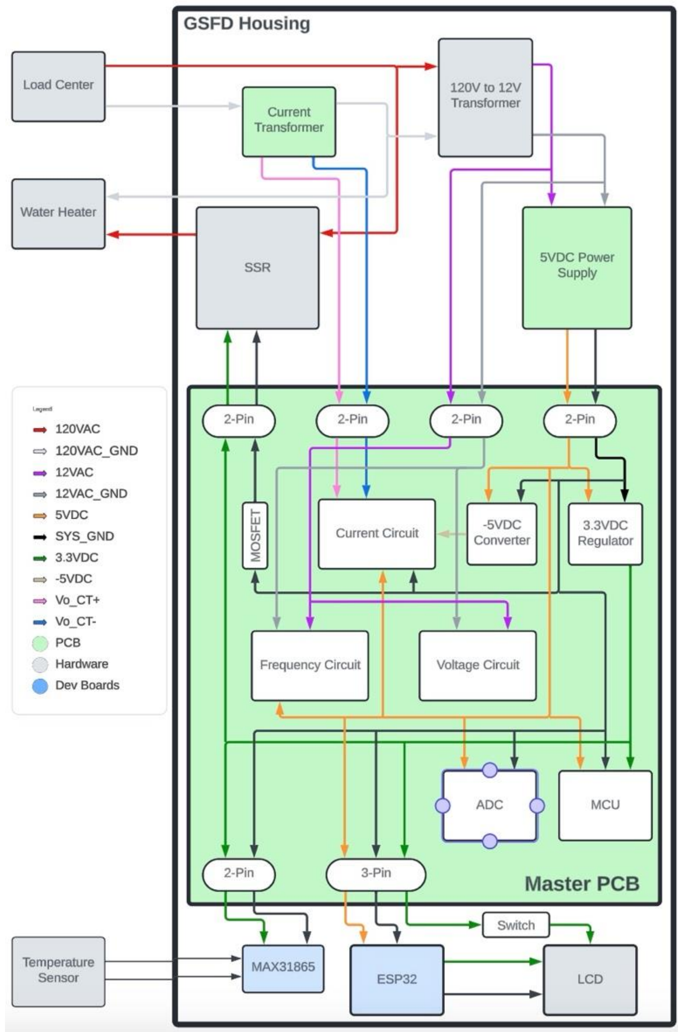


Fig. 12. Power Supply Flow Chart.

IX. *PCBs*

A. *Step-Down PCB*

The Step-Down PCB serves two main functions. The first function is to convert the 12vAC signal to a usable 5vDC to provide power to the Master PCB. The second function is to act as an electrical separation between the step-down circuit and the sensitive measurement circuits. The step-down PCB is 2 layers and houses a full wave rectifier made with diodes to rectify the incoming signal and a lm7805 linear voltage regulator to provide a stable 5vDC output. The output of this board connects to the 5v input on the master PCB.

B. *Current Transformer PCB*

The current transformer PCB houses the through hole transformer were using to measure the current draw of the load. This board features a +/- 0.5% tolerance 100ohm resistor. The accuracy of this resistor is important because it ensures linearity. The output of this board connects to the CT input on the Master PCB. The design decision to separate the CT onto its own board was due to the concern of high voltages and currents of the load line being near the measurement circuits. The separation to its own PCB helps to ensure the measurement circuits on the Master PCB are more accurate and reliable.

C. Master PCB

The master PCB was designed to integrate various essential circuits, including those for measuring voltage, current, and frequency along with all the connections for the ADC and MSP. This PCB also provides power and enables connectivity to all auxiliary components such as the temperature sensor, ESP32 and MAX31865.

A notable feature of the PCB design is the ability to utilize the external ADC by disconnecting the BYP-OUT pins and connecting all the JMP+ and JMP- pins. Additionally, there is a disconnect jumper to disconnect the 5v power to the ADC directly. The team originally decided to use an external 24-bit ADC for more accurate measurements, but due to time constraints we are instead using the onboard ADC on the MSP430F5529. With this decision, the board can support both options for future teams that may pick up this project. Additional features include many testing points and disconnects at critical parts of the circuits, such as the ability to disconnect each measurement circuit individually or disconnect 5v, 3.3v and -5v independently.

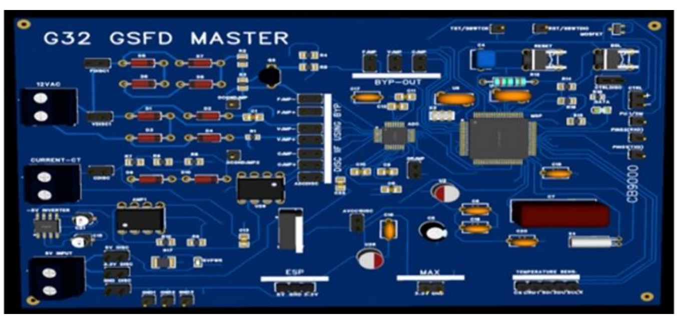


Fig. 13. 3d model of master PCB

X. System Testing

This section describes the comprehensive evaluation approach taken to validate the functionality and performance design. Each testing phase, from component-level assessments on breadboards to the integration testing of the master Printed Circuit Board (PCB), is detailed, highlighting the systematic verification of the design and operational criteria.

A. Component-Level Prototyping

Initially, the systems core circuits were assembled on breadboards using the adjustable bench DC power supply to supply power to the active components. This phase facilitated the validation of the voltage, current, and frequency measurement circuits, using a function generator to simulate varying grid conditions. This testing confirmed the circuits' capabilities and ensured the systems analog readings were accurate.

B. Semi-Permanent Assembly Verification

Following the breadboard prototyping, circuits were transitioned to stripboards for a more durable assembly. This stage served to evaluate the circuits' performance in a semi-permanent configuration, introducing a power supply unit to the testing framework. The PSU incorporated a transformer to do the main step down from 120v, then rectification, filtering, and regulation to 5V, which we then used to power the active components in the system.

C. PCB Integration

After validating the stripboard assemblies, individual PCBs for each circuit were designed and fabricated. This step allowed for isolated testing of each component within an environment that closely mimics the final deployment scenario. We also ordered a custom breakout board that included the MSP430F5529 and other necessary components to serve as the central processing unit of the system

D. Embedded System and Interface Evaluation

The embedded system and user interface were first tested using a MSP430F5529 launchpad board, so that we could get a head start on the coding and the algorithm involved before transitioning to the breakout PCB board. This testing phase focused on the integration and validation of the analog values coming into the MSP430 and doing the appropriate scaling and coding to ensure that the values were accurate.
We also did extensive testing with the LCD display and temperature measurement functionality which utilized a ESP32 Dev board for communication and accurate data representation between the microcontroller unit (MCU), the LCD, and the temperature sensor.

E. Final System Integration Testing

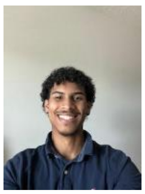
The culmination of the testing process involved the assembly and evaluation of the Master PCB, integrating all previously validated circuits into a comprehensive system. This final testing phase verified the functionality of each component and the system's overall functionality, showing the design capacity to function in accordance with design specifications.

XI. Conclusion

In conclusion, the development of the GSFD signifies a considerable achievement for the team, particularly given the initial limited exposure to grid stabilization technology. This endeavor required us to research the dynamics of grid stress, the implications of load management, and the complex workings of stochastic control systems. The integration of these components highlights our dedication to advancing sustainable energy solutions. Through a concerted group effort, we completed the bulk of design for a device with the potential to make a meaningful impact on energy consumption and grid stability.

XII. Biography

Briggs Green is a senior Electrical Engineering Student who is graduating in May of 2024. During his internship in the Power and Renewable Energy sector, he enjoyed power flow analysis, load simulations and design.



Alex Cruz is a senior Computer Engineering student who is graduating in May of 2024. His plans include learning about cybersecurity and obtaining certifications while working as a software engineer to gain experience.

Aymes Glidewell is a senior Electrical Engineering student set to graduate in May 2024, with an interest in hardware design and testing. This focus is complemented by a passion for audio and music. Previous projects include the design and exploration of audio equipment and electronic musical instruments which provide a solid background in circuit analysis and signal processing.

Eric Doolin is a senior Electrical Engineering student focusing on Power and Renewable Energy. His passions include grid-edge hardware design, distributed energy system analysis, and environmental problem solving. Previous projects include a portable, modular solar generator and the Seminole State College Oviedo Campus Clock Tower Solar Conversion project.

XIII. Acknowledgements

The authors would like to acknowledge their sponsors, Dr. Qun Zhou Sun and Dr. Tian Yu, for formulating and presenting this idea.

Also deserving of thanks is Dr. Chung Yong Chan for his incredible insight and for teaching us how to present this project smoothly and professionally.

We would also like to acknowledge Dr. Arthur Weeks for his countless hours in the lab helping anybody in any way that he could.

We offer our gratitude to any professor that has offered any advice or help whenever we approached them with a request.

Lastly, we would like to thank our friends and family for supporting us during this important time.

XIV. References

[1] G. Tian and Q. Sun, "A Stochastic Controller for Primary Frequency Regulation Using ON/OFF Demand Side Resources," IEEE Transactions on Smart Grid, vol. 14, no. 5, p. 4141-4144, September 2023.

[2] M. Pauluk, P. Piątek, and J. Baranowski, “Efficient Zero-Value-Cross Detection for Single-Phase Mains-Powered Motors: A Comparative Study,” Energies, vol. 16, no. 17, p. 6298, Aug. 2023, doi: 10.3390/en16176298.

[3] Texas Instruments. "MSP430F5529 Mixed-Signal Microcontroller." Texas Instruments. [Online]. Available: https://www.ti.com/product/MSP430F5529#:~:text=,parameters%2C%20ordering%20and%20quality%20information.