Fuel Cell Monitor

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CONCEPT OF OPERATIONS

REVISION – Draft
03 October 2022

CONCEPT OF OPERATIONS
FOR
Fuel Cell Monitor

TEAM 38

APPROVED BY:

_____
Project Leader Date

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Prof. Kalafatis Date

_____
T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	[09/15/2022]	Fuel Cell Monitor System		Draft Release
2	10/02/2022	Russell Wells		FSR, ICD attachment

Table of Contents

List of Tables

No table of figures entries found.

List of Figures

1. Executive Summary

A single fuel cell is an easy power source to monitor, but to achieve any level of real usable power they must be connected in a stack which provides a usable amount of power. Our fuel cell monitor will be focused on the integrity of individual cells. The proposed device will monitor individual voltages on a real time basis, transmit the data via Wi-Fi to a mobile app which will have a graphical display of the individual cell voltages.

2. Introduction

Fuel cell monitor is used to measure the efficiency and electrical characteristics of fuel cells [2]. A Fuel cell is an electrochemical energy conversion device where it utilizes hydrogen and oxygen to generate electricity, heat, and water [3]. The fuel cell monitor that will be created will provide real-time monitoring of every cell in each fuel stack. This monitor will be able to communicate via Wi-Fi to transfer the data from the cell to an application. The purpose of this monitor is to track the fuel cells to see if they fail at some point.

2.1. Background

Fuel cells are not new technology, and neither are fuel cell monitors. However, with the more recent push for clean and renewable energy, different types of fuel cells have become much more prevalent in research as well as personal use of recreational equipment. Some of the fuel cells take hydrogen and use it to generate electricity. The fuel cell monitor will be used to track these voltages. The monitor will have a microcontroller unit which will be used to store the data from the fuel cell.

2.2. Overview

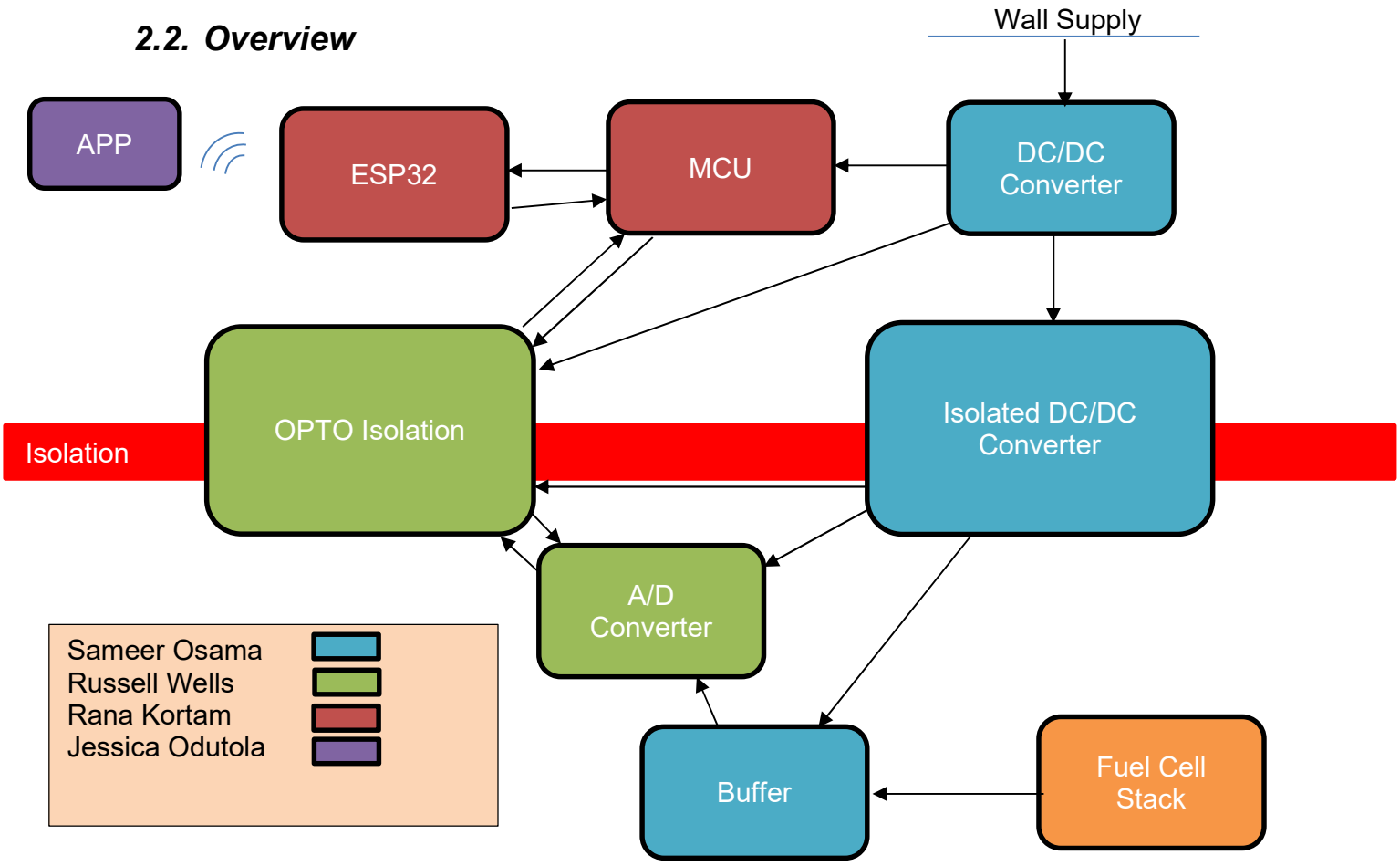

Figure 1: Fuel Cell Monitor Block Diagram

The proposed device is not intended as a replacement for a more robust control system such as SCADA but is intended as an affordable, low maintenance, mobile, voltage monitoring and alarm system. The system will display real-time voltages on the app and push notifications to the user via the app when a cell is not operating within expected ranges. The monitor will not have a control aspect but will send a warning to the owner/operator when action is required to preserve fuel cell integrity.

The app is going to allow real-time monitoring as well as provide historical trend data that can be used to diagnose current issues and anticipate future failures based on past experiences.

2.3. Referenced Documents and Standards

[1] Marsh, Jane. "5 Hydrogen Fuel Cell Environmental Impacts." *Environment Co*, 19 Nov. 2020, https://environment.co/hydrogen-fuel-cells-environmental-impacts/.

[2] "Fuel Cell Monitor Pro 4.0." *Fuel Cell Store*, https://www.fuelcellstore.com/fuel-cell-monitor-pro-3-u103.

[3] "Fuel Cell Basics." *Fuel Cell & Hydrogen Energy Association*, https://www.fchea.org/fuelcells.

3. Operating Concept

3.1. Scope

The scope of this project is to provide a monitor that will be able to transfer all relevant parameters to track fuel cells. The exact deliverables for the scope of this project are as follows:

- Power system development
- Internal signal transfer and manipulation development
- Microcontroller development
- Application development

Documentation for the design, construction, and programming of the units will be provided for all parts of the project.

3.2. Operational Description and Constraints

The fuel cell monitoring system is intended for use in a controlled laboratory or secure location. The system will include Wi-Fi-enabled data transfer from the device to a user's cell phone.

Constraints:

- The device is not intended for use outdoors or in harsh environments
- The device requires a 110Vac wall outlet for power

3.3. System Description

- Power System: A wall wart power supply will be used to convert the AC voltage to DC voltage. This DC voltage will be passed through multiple DC/DC converters to bring the voltage down to different levels. The new lower voltage levels will be supplied to the microcontroller, the opto-isolator, and the isolated DC/DC converter. The isolated DC/DC converter is used to pass power over the isolation line and provide power to the op-amps and the ADC.

- Internal Signal manipulation and transfer: The voltages from the fuel cells will be passed through an op-amp buffer to an analog to digital converter. The converter will send the digital signal to an opto-isolator which will transfer the signal as a scaled current that is representative of the differential voltage.

- Signal Processing: The signal from the opto-isolator will be sent to the microcontroller unit where the data will be stored. Then, the microcontroller will be connected to another microcontroller, ESP32, with a UART where the data will be transferred to the application.

- Application and graphical display: The application will display the voltages in the form of a graph of each fuel cell in the stack to the user. The user will be able to navigate to the fuel cell of their choice and/or the fuel cell stack to view the voltages.

3.4. Modes of Operations

- Normal Operating Mode: All cells are within a preset range and the data is displayed graphically on the App.
- Cell Alarm Mode: One or more of the cells have fallen below threshold voltage or spiked above. App will display the faulty or over loaded cell as defective.
- System Alarm Mode: The app no longer receives information from the system outside of normal disconnect.

3.5. Users

- Initial Installer: An electrician or fuel cell technician should conduct the initial installation and test.
- General Operator: The normal operator of this device will not require training. Anyone with access to an android smartphone will be able to connect to the device through the app and monitor the system.
- Maintenance Technician: Maintenance on the device, beyond.

3.6. Support

User will be given a parts list with all replaceable parts outlined for purchase. These parts would include the wall power supply, type and quantity of external signal wires, and a component list for all major PCB components. The program for the microcontroller and App will not be supplied

4. Scenario(s)

4.1. Experimental Lab Equipment

Our project, although not all inclusive, will be relatively inexpensive and less concerning when connected to experimental fuel cell systems. The use of the application as a monitoring system will also allow the user to monitor the fuel cells and maintain historical data even if left alone for an extended period.

4.2. Personal or Home Power Generation

The system could be used by a homeowner or non-commercial entity where an individual would like to be able to monitor a fuel cell stack.

5. Analysis

5.1. Summary of Proposed Improvements

An improvement that the proposed system will provide is the mobile app connectivity. Another improvement is cost efficiency.

5.2. Disadvantages and Limitations

The limitations of the Fuel Cell Monitor include:

- The app used to monitor and display the voltages for each individual fuel cell is only available on Android devices.
- To use our monitor, it is necessary to be near an outlet.
- The monitor cannot be used outdoors.

5.3. Alternatives

- Full monitor and control system would be an alternative. A PLC cabinet with SCADA control nodes for back pulse and temperature regulation as well as full power monitor would be an alternative and would do the job of our proposed device but at a much higher cost to the client in both initial implementation as well as annual maintenance.

5.4. Impact

[1] Fuel cells, depending on where the hydrogen is extracted, have a positive impact on the environment. Hydrogen can be found in most things in nature; therefore, hydrogen fuel cells are a renewable resource. The ubiquity of hydrogen in nature means that the fuel cells are also a sustainable resource. The use of hydrogen fuel cells significantly reduces carbon emissions. In comparison to their alternatives, fuel cells are the best option for the environment. Being able to monitor the levels of the fuel cells ensures that the negative effects on the environment are limited.

Fuel Cell Monitor

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FUNCTIONAL SYSTEM REQUIREMENTS

FUNCTIONAL SYSTEM REQUIREMENTS
FOR
Fuel Cell Monitor

PREPARED BY:

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Author Date

APPROVED BY:

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Project Leader Date

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John Lusher, P.E. Date

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T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	10/03/2022	Fuel Cell Monitor System		Draft Release

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1. Purpose and Scope

Monitoring a fuel cell to make sure it doesn't fail or give a different voltage than expected is important to the fuel cell stack. Our aim is to provide a fuel cell monitoring system that will take the readings from each fuel cell in the fuel cell stack and to monitor these readings through an application. With our system, the voltage will be taken from the fuel cell stack and then passed through a differential amplifier to filter the noise. The signal will then go to the microcontroller via ADC and opto-isolator which provide a signal the processor can read and protect in the event of a short or cell malfunction. Then, the microcontroller will send the data to the ESP32 which will communicate with the app to display the voltage for each fuel cell in the stack.

Figure 1. Fuel Cell Monitor Conceptual Image

1.2. Responsibility and Change Authority

Subsystem	Responsibility
Power System Development	Sameer Osama
Internal Signal Transfer and Manipulation Development	Russell Wells
Microcontroller Development	Rana Kortam
Mobile Application Development	Jessica Odutola

Table 1: Subsystem Leads

2. Applicable and Reference Documents

2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title

Table 2: Applicable Documents

2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title

Table 3: Reference Documents

2.3 Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings, or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

3. Requirements

3.1. System Definition

The Fuel Cell Monitor is a practical and reliable system. It allows users to observe voltage variations on each individual fuel cell via mobile app. The Fuel Cell Monitor has four sub-systems: Power System, Internal Signal Transfer and Manipulation, Microcontroller, Application Development.

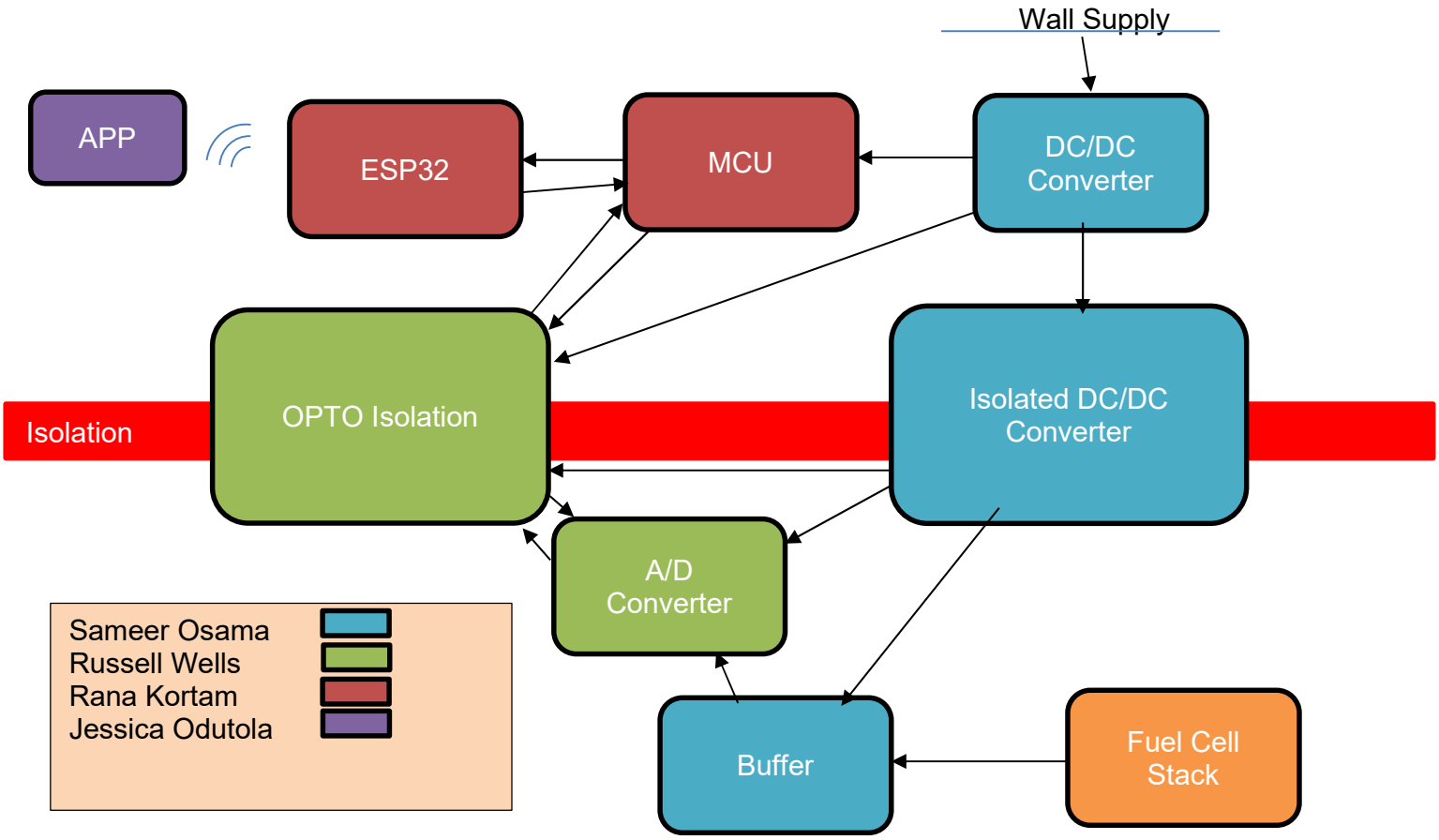

Figure 2. Block Diagram of System

In figure 2, the block diagram above shows the different subsystems within the Fuel Cell Monitor. The power for the whole system will be provided by a wall supply, which will be then converted to DC voltage using a DC/DC converter. The voltage reading will be taken from the fuel cell, and it will pass through the buffer to reduce noise. The signal will then be passed to the microcontroller via ADC and opto-isolator which provide a signal that processor can read as well as protect in the event of a short or cell malfunction. Then, the microcontroller will send the data to the ESP32 which will communicate with the app to display the voltage for each fuel cell stack.

3.2. Characteristics

3.2.1. Functional / Performance Requirements

3.2.1.1. Fuel Cell Monitor Voltage Range

The fuel cell monitor system shall be capable of monitoring voltages ranging from 0 VDC to +5 VDC.

Rationale: The requirement specified by the client was roughly 0.7 VDC. However, the capabilities of the parts used in the system allow for a higher range of voltage inputs.

3.2.2. Operating Environment

The fuel cell monitor shall be capable of operating within a controlled laboratory or under non-environmentally harsh conditions.

Rationale: The client specified a laboratory environment in which fuel cells are being used for experimentation.

3.2.3. Physical Characteristics

3.2.3.1. Mass

The mass of the Fuel Cell Monitor shall be less than or equal to 0.25 kilograms.

Rationale: This is a requirement specified by our customer due to constraints of their system in which the Fuel Cell Monitor is operating.

3.2.3.2. Volume Envelope

The volume envelope of the Fuel Cell Monitor system shall be less than or equal 0.125 cubic feet.

Rationale: The monitoring system is intended to be simple and capable of monitoring multiple fuel cell types in multiple stack configurations. The monitor must be small enough to sit inside the stack enclosure or near it without interfering with stack operation and maintenance.

3.2.3.3. Mounting

The fuel cell monitor will be designed to sit on a shelf or the floor inside the fuel cell housing

Rationale: This is a requirement of the client. The system is also compatible with any fuel cell stack producing voltages within the specified range and universal mounting is outside the project's scope.

3.2.4. Electrical Characteristics

3.2.4.1. Signal Inputs

The inputs of the system will be voltages transferred directly from the fuel cells to the monitor system via signal wire.

Rationale: This is a necessity given the nature of the monitor system

3.2.4.2. Power Consumption

The maximum peak power of the system shall not exceed 3 Watts.

Rationale: Although the major components have been determined, the minor components have not. % Watts is expected to be much higher then is necessary.

3.2.4.3. System Voltage Input

The input voltage level for the Fuel Cell Monitor System shall be +2.7 VDC to +5.5 VDC.

Rationale: This is a requirement outlined by the client and constrained by the usable parts.

3.2.4.4. Data Output

The Fuel Cell Monitoring System shall include an android application for users to view alerts if a fuel cell fails. The android application shall display the voltage levels of both the stack and the individual fuel cells.

Rationale: The Search and Rescue information passes directly to the customer's system.

3.2.4.5. Diagnostic Output

The Fuel Cell Monitoring System shall include a diagnostic interface for control and data logging.

Rationale: Provides the ability to control things for debugging manually and a way to view/download the node map with associated potential targets.

3.2.5. Environmental Requirements

The Fuel Cell Monitoring System shall be designed to withstand and operate in the environments specified in the following section.

3.2.5.1. Thermal

The Fuel Cell Monitoring System shall be able to function in environments ranging from -40°C to 85°C.

Rationale: The range of temperatures is provided in the datasheets of the system components.

3.2.5.2. Water Damage

The Fuel Cell Monitoring System will be capable of withstanding small non continuous splashes or misting with water.

Rationale: Given the nature of fuel cells such as hydrogen fuel cells. It is necessary to ensure the device is not susceptible to minor exposure to water.

4. Support Requirements

The Fuel Cell Monitoring system requires an internet connection to interact with the applications to give notifications. User must provide WI-FI and a wall supply to supply power to the rest of the system.

Appendix A: Acronyms and Abbreviations

BIT	Built-In Test
CCA	Circuit Card Assembly
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO/IR	Electro-optical Infrared
FOR	Field of Regard
FOV	Field of View
GPS	Global Positioning System
GUI	Graphical User Interface
Hz	Hertz
ICD	Interface Control Document
kHz	Kilohertz (1,000 Hz)
LCD	Liquid Crystal Display
LED	Light-emitting Diode
mA	Milliamp
MHz	Megahertz (1,000,000 Hz)
mW	Milliwatt
PCB	Printed Circuit Board
RMS	Root Mean Square
TBD	To Be Determined
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
VME	VERSA-Module Europe

Appendix B: Definition of Terms

Fuel Cell Monitor

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Sameer Osama
Jessica Odutola

INTERFACE CONTROL DOCUMENT

REVISION – Draft
03 October, 2022

INTERFACE CONTROL DOCUMENT
FOR
Fuel Cell Monitor

PREPARED BY:

_____
Author Date

APPROVED BY:

_____
Project Leader Date

_____
John Lusher II, P.E. Date

_____
T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	[10/01/2022]	Fuel Cell Monitor System		Draft Release

Table of Contents

List of Tables

No table of figures entries found.

List of Figures

No table of figures entries found.

1. Overview

The following sections outline the physical, electrical, and communication characteristics of the fuel cell monitor System. Some of the fields outlined below are subject to change depending on availability of parts and part characteristics

2. References and Definitions

Provide any references (i.e., standards documents) and definitions. Examples are shown below.

2.1. References

Not Applicable at this time.

2.2. Definitions

ADC	Analog to digital converter
mA	Milliamp
mW	Milliwatt
MHz	Megahertz (1,000,000 Hz)
TBD	To Be Determined
TTL	Transistor-Transistor Logic
VME	VERSA-Module Europe

3. Physical Interface

3.1. Weight

The weight of the system is unknown at this time but is expected not to exceed 2lbs.

3.2. Dimensions

Dimensions are unknown at this time, but the volume is expected not to exceed 0.125 cubic feet. FSR will be updated when dimensions are known

3.3. Mounting Locations

Specific mounting options will not be considered for this system.

4. Electrical Interface

4.1. Power

4.1.1 Primary Input Power

Primary input power shall be from a standard wall outlet through a wall wart AC to DC converter which will bring down the voltage to 12 VDC.

4.1.2 Internal Power

Internal power shall be regulated through DC-DC converters and stepped down to voltages ranging from +2.7 to +5.5 VDC.

4.2. Signal Interfaces

4.2.1 Raw Data Signal Interface

The voltages from the fuel cell will be passed to the monitor system via signal wire to PCB mounted terminal block.

4.2.2 Internal Data Signal Interface

The internal signal shall be transferred to the microcontroller via Op-amp filter, ADC, and opto-isolator.

4.3. User Control Interface

4.3.1 User Graphical Interface

The android application shall display voltages for both the fuel cell stack and the individual fuel cells. The user shall receive alerts when errors occur with the fuel cells.

4.3.2 User Control Interface

The app shall allow the user to set both low and high point alarms.

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5. Communications / Device Interface Protocols

5.1 Wireless Communications (Wi-Fi)

The microcontroller has a built-in Wi-Fi module using IEEE 802.11 b/g/n standards. This connection will be used to send a user android application for review.

5.2 Device Peripheral Interface

The MCU will connect to the ESP-32 microcontroller through a UART port. This allow to transfer the signal from the MCU to the ESP-32 microcontroller to send the signal to the application.

Fuel Cell Monitor System

Rana Kortam, Russell Wells, Sameer Osama, Jessica Odutola

SCHEDULE

Revision – 1

3 October 2022

Fuel Cell Monitor Execution Plan Fall 2022

	9/5/2022	9/19/2022	10/3/2022	10/17/2022	10/31/2022	11/14/2022	11/28/2022	DATE				
Understand Project Problem												
Project design Overview												Completed
Divide Into Subsystems												In Progress
ConOps Report												Not Started
Determine Microcontrollers in use												Behind Schedule
Create Major Parts List												
FSR, ICD Report												
Midterm Presentation												
App displays "Hello World"												
Simulate components for Power												
Learn IDE to code microcontroller												
Determine External signal wires and wire terminal block												
Order Major Parts												
Create PCB Schematic												
Dtermine PacTec Enclosure Needed												
Order PCB												
Order PacTec Housing												
App displays Home Page												
Status Update Presentation												
App GUI is 50% completed												
Create code for PIC32												
Final Presentation												
Final Demo												
Final Report												

Fuel Cell Monitor System

Rana Kortam, Russell Wells, Sameer Osama, Jessica Odutola

VALIDATION PLAN

Revision – 1

3 October 2022

Fuel Cell Monitor Validation Plan

Paragraph #	Test Name	Success Criteria	Methodology	Status	Responsible Engineer(s)
3.2.4.2	Power Devices On PCB	PCB transfers power without overheating or burnout	Power Board and watch, smell, listen	Untested	Russell, Sameer
3.2.1.1	Internal signal voltage range	System can properly handle the specified voltages with minimal difference between tests.	Introduce voltages of 0-5V and measure output signals	Untested	Russell
3.2.1.1	Differential voltage tests	Pass a differential voltage through the Opamp buffer and receive the proper digital signal from the optoisolator	Introduce a range of voltages including edge cases and ensure proper output	Untested	Russell, Sameer
3.2.4.4	Android application graphical functionality	Application can properly display accurate voltage levels to user.	Use application on android device and verify volatages are accurately displayed	Untested	Jessica
3.2.4.4	Android Application alarm functionality	Application send alarm to user when voltage goes above or below ranges	Add set points to app and introduce alarm level voltages	Untested	Jessica
3.2.4.2	Power system functionality test	Power is applied from wall outlet and proper power transfer is read at outputs	Apply power to system and read voltage output at device trace	Untested	Sameer
3.2.4.1	Opamp system functionality test	Differential voltages are passed to the opamp and expected voltage is seen on the output	Power opamps and apply varrying differential voltages and read output voltage	Untested	Sameer
N/A	PIC32 Microcontroller functionality test	The code for recieving the voltage signal for data acquisition	PCB board and coding on IDE	Untested	Rana
N/A	ESP32 Microcontroller functionality test	The code for communicating with the application	PCB board and coding on IDE	Untested	Rana