Introduction

Problem

Unstable power for electric machinery is a common problem in the industry. Unstable power causes power outages or fluctuations which could be harmful to the machinery and the people around it. In a large factory, for example, a power outage can cause hours of downtime and thousands of dollars to be lost. This problem is vital as it could cause permanent damage to both the machinery and the people using it.

Solution

This team will work under the supervision of Oscar Azofeifa, the founder of PowerBox Technology, in order to create a power meter for the PowerBlock. This power meter is to be used in an industrial setting, ensuring that the high-power machinery receives a consistent, clean source of energy.

This power meter will connect to the 3-phase output of an inverter and will be used to measure the 3-phase RMS current / voltage, real power, reactive power, and apparent power. The voltage/current will also get stepped down and outputted to be used as an instruction signal for a DSP. All of our data will be recorded for use in optimizing power delivery to the machinery that requires it.

Visual Aid

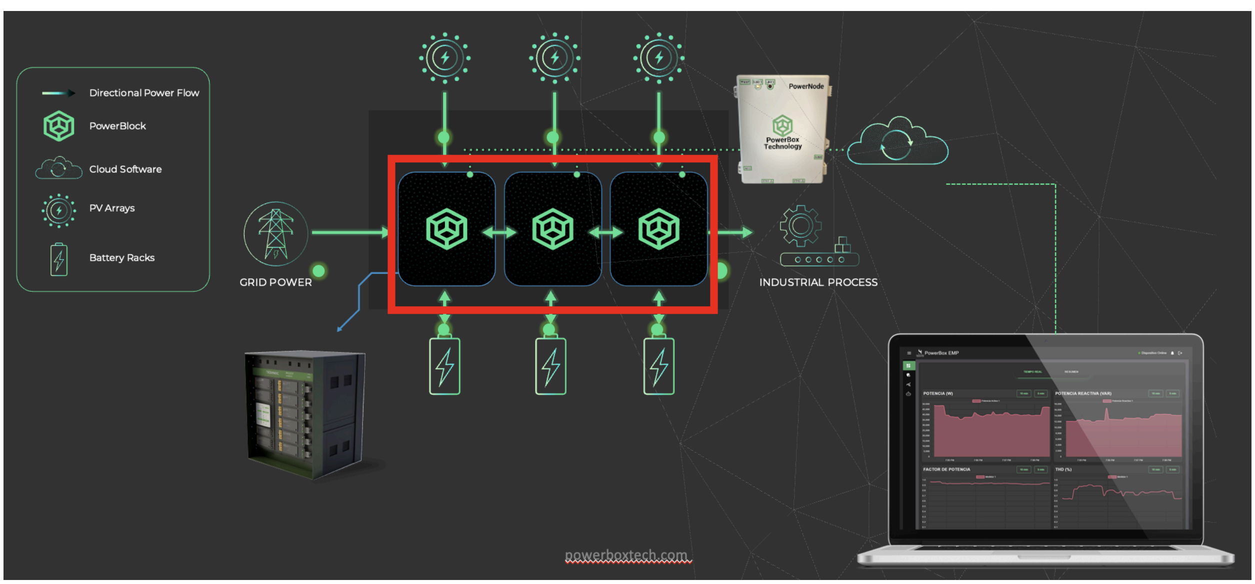

Figure 1. PowerBox Technology helps modernize factories' electrical systems through the PowerBox Energy System. This is a diagram of what the company does as a whole. The PowerBlock (inside red borders) is what the company works on.

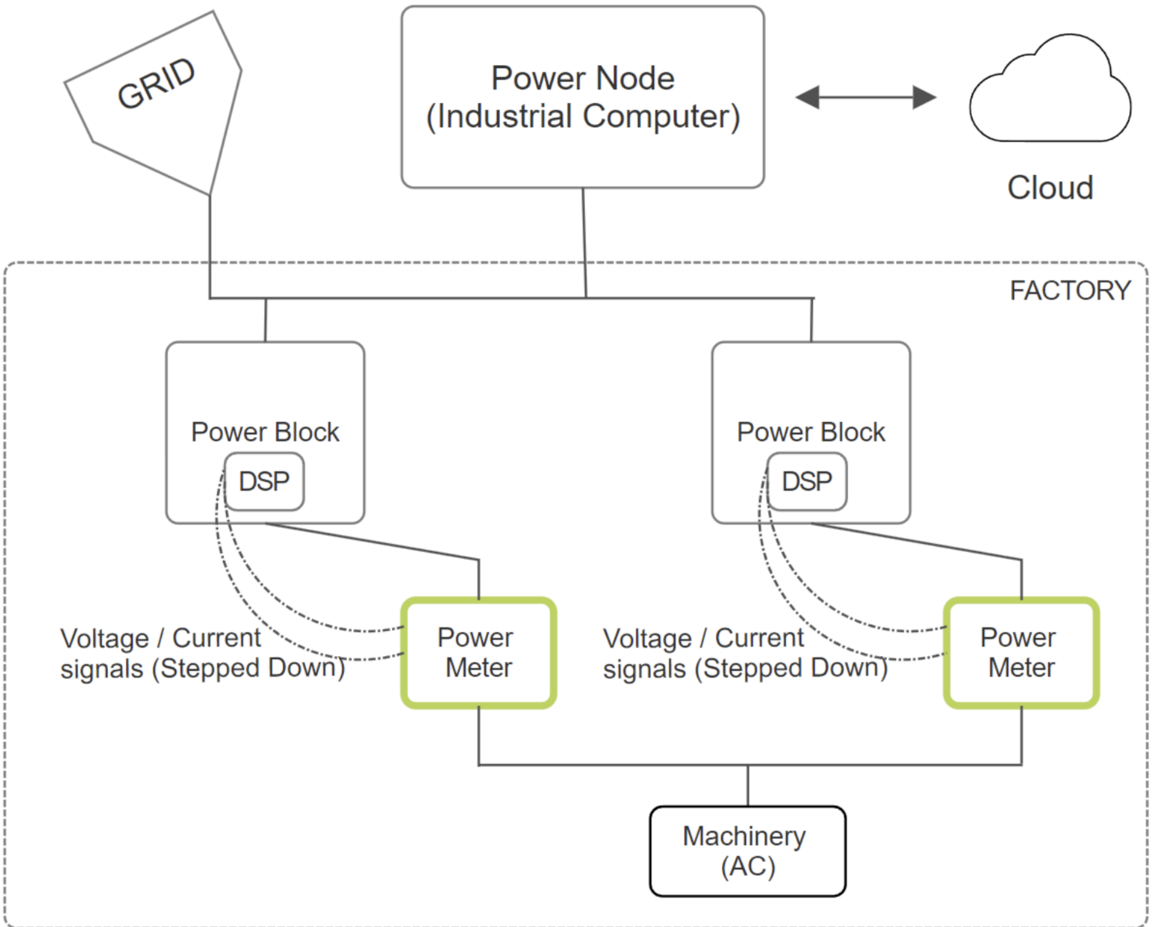

Figure 2. This is a visual representation of how our power meter fits into the system. The power meter is outlined in green and is between the power block and the machinery.

High-level Requirements List

- The Power meter will receive the following information:
  - Three phase voltage readings of the system.
  - Three phase current readings of the system.
- The Power meter will output the following information:
  - Three analog current and voltage signals which have been stepped down from the inverters high voltage/current readings.
  - Real Power of the system.
  - Reactive Power of the system.
  - Per phase voltage readings of the system.
  - Per phase current readings of the system.

- The current analog outputs should be within +-1% of the actual value. This can be checked using the rated current.
- The voltage analog outputs should be within +-1% of the actual value.
- The real power should be within +-1.41% of the actual value.

This is according to the IEC accuracy standard and is what is expected from PowerBox Technology.

Design

Block Diagram

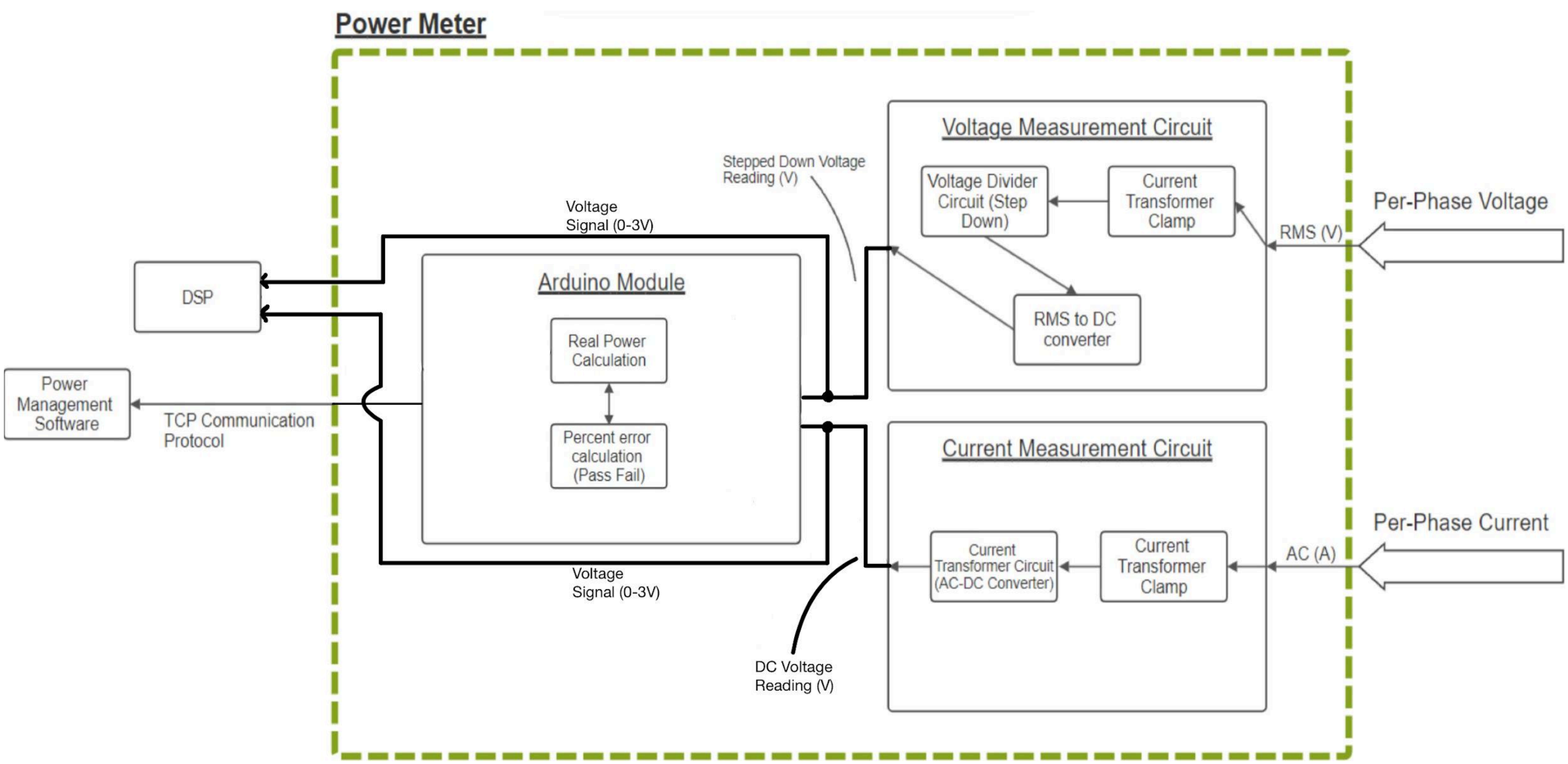

Figure 3. The power meter includes the blocks in the dashed green lines.

Subsystem Overview

RMS Voltage Measurement Circuit

The RMS voltage measurement circuit uses the output of the inverter to measure the three-phase voltage. This and the AC current measurement circuit will be used to calculate the real power, reactive power, and apparent power. This circuit will also step down the voltage and output three analog signals to the digital signal processor. This high voltage will be stepped down to a value that can be outputted as a signal through the use of a voltage divider circuit. In order to safely do this, we will also incorporate regulators and protection circuits.

AC Current Measurement Circuit

The current for the three phases will be going through current transformers, then to the AC current measurement circuit. The current transformer is used to accurately monitor the current while not damaging the equipment with the high current flow. The AC current measurement circuit and the RMS voltage measurement circuit will be used to calculate the real power, reactive power, and apparent power. The circuit will also step down the current and output three analog signals to the digital signal processor. The current transformer is given in this project, but we will have to set the current limits. We will include circuitry that will ensure that the stepped-down values are clean and accurate. These may include precision regulators, overcurrent protection, and low-pass filters.

Power Calculation (Arduino)

This part of the interface board will take the voltage and current from the previous circuits and calculate real power, reactive power, and apparent power. The power data will be recorded, which can be done with an Arduino board, and the power data can be stored in registers for the other software to use. The Arduino works as the brain of the power meter, it is connected to the circuitry of the meter to store and analyze voltage readings, and it sends the power data through a communication protocol to the Power Node for storage and distribution to other servers. We will use a communication protocol like Modbus TCP to transmit the power data (real power, reactive power, and apparent power) from the power calculation subsystem of the power meter to the Power Node. Modbus TCP is a well-established protocol in industrial environments and provides a reliable solution for data transmission. The Arduino board (or an equivalent microcontroller) will be equipped with an Ethernet shield to support TCP/IP communication. It will interface with the power calculation circuit to collect power data while the Ethernet connection will facilitate communication using Modbus TCP. The Arduino will act as a Modbus TCP server that regularly updates power parameters, sending data in response to requests from the Modbus TCP client of the Power Node.

Subsystem Requirements

1. RMS Voltage Measurement Circuit:
    a. The fixture must be able to measure the three-phase RMS voltage with an average error percentage of ±1% as per the IEC's standards.
    b. The high voltage output of the inverter should be stepped down using a step-down inverter. These stepped-down voltage values are to be used as input signals for the DSP. Voltage regulators and protection circuits will be incorporated as well.
2. AC Measurement Circuit:
    a. The subsystem should be able to measure the AC current with an error percentage of ±1% as per the IEC's standards.

b. The current should be stepped down to a suitable value for the power meter to send analog signals to the DSP.

3. Power Calculation Circuit:
    a. The subsystem should be able to calculate the power (real, reactive, and apparent) with an error percentage of ±1.41% as per the IEC's standards.
    b. The subsystem should be able to record the power data for other uses if necessary.
    c. The subsystem should be able to transmit power data from the Arduino to the Power Node for storage and distribution.

Tolerance Analysis

Some critical aspects that are needed to define the successful completion of the project are the accuracy of the measurement circuits, power calculation, and data transmission. Every one of these aspects is to meet the accuracy standards imposed by the IEC. As per the IEC's standards, all current, voltage, and power measures should fall within an error margin of ±1%. This tolerance analysis will quantify the worst-case scenarios and will ensure that our design can handle those conditions without exceeding the determined error margins.

1. Voltage and Current Measurement Circuits:
    a. The voltage and current measurement circuits work to step down the values read from the three-phase inverter to levels appropriate for analog signal processing. These values all need to follow a percent error accuracy of ±1% as per the IEC's accuracy standard.

    The percent error margin of both the voltage and current measurements can be

$$E = \left(\frac{V_{\text{measured}} - V_{\text{actual}}}{V_{\text{actual}}} \right) \times 100$$

    calculated using the following equation:
    In this equation, the values of "V" can be either the voltage or current readings.

    Measured Values are the ones that are recorded when the fixture is run.

    Actual Values are the values that are expected based on the known parameters.

    To prevent the worst-case scenario, we can calculate the maximum allowable voltage / current deviation and compare this to our recorded values as well. We can do this by multiplying our actual value by 1%. For example, if our expected value is 500V, we multiply it by .01 which gives us a value of 5V. This means that the range of allowable measured values is from 495V - 505V. Again, the same equation can be applied to current readings. If our actual current is 50A, then our range of allowable measured values is from 49.5A to 50.5A.

The stepped-down values thus require high precision. This means that interference and fluctuations will be mitigated with filtering and regulating circuitry.

One specific detail to recognize is that the Power Meter assumes the inverter is running in ideal circumstances. We sort and analyze our recordings through our circuit and ensure that compared to "ideal" outputs the values that we are reading are as close to this ideal output as possible.

2. Power Calculation:

$$P = V_{\text{rms}} \times I_{\text{rms}} \times \cos(\theta)$$

a. Real Power will be calculated using the following formula:
Where Vrms and Irms are the measured values. Cos(theta) is the Power Factor.

In order to find the percent error of the Real power, we use the following equation:

$$E_P = \sqrt{\left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta I}{I}\right)^2} \times 100$$

In this equation, the Delta values are the maximum allowable voltage / current error deviations previously calculated, while the I and V are the expected current and voltage values.

If we assume that the error for both our current and voltage values are at their 1%

$$E_P = \sqrt{(0.01)^2 + (0.01)^2} \times 100 = \sqrt{0.0002} \times 100 \approx 1.41\%$$

maximum, the percent error value for Real Power will actually be different.

This means that our maximum percent error value for Real Power will always be at a maximum of ±1.41%.

Ethics and Safety

One ethical issue involves the responsibility to design and implement a safe and reliable system, as outlined in the IEEE Code's principles of prioritizing the safety, health, and welfare of the public.[3] The potential misuse of our power meter, such as improper installation, could lead to inaccurate power measurements or electrical hazards, causing harm to operators or damaging equipment. To prevent such incidents, we will conduct comprehensive testing and documentation to ensure that users are well-informed and can operate the power meter safely. Safety concerns that involve high voltages are also important. We will follow established safety standards at the PowerBox Technology lab, which provide guidelines and training that we have already done to protect against electrical shock, fire, and equipment damage.

The main code of conduct followed when working with power is the OSHA. When working with any type of equipment in a lab, it is important to keep the space clean and clear of obstructions. The floor of the workspace should be clear, dry, and free of hazards such as sharp objects, leaks, water, etc. The workspace should be inspected and maintained regularly.[4]

Another important issue for working with high-voltage equipment is personal protective equipment (PPE). Training should be done on when and how the PPE should be used.[5] There should be appropriate eye, face, head, foot, and hand protection worn while working. More specifically, the PPE we will be using is the electrical protective equipment. The design and electrical requirements of the electrical protective equipment should be met.[6]

When there is an emergency, there should be an emergency plan for the lab. The safety exit should not be blocked and must be unlocked.[7] Since we are working in the POETS Research and Development Center, we will be following their emergency plan. If the emergency plan is changed, we need to be responsible for learning the new action plan as necessary.

Finally, we will be designing and implementing systems that are robust and secure and avoid harm to others according to the ACM code of conduct.[2] We will prioritize the well-being of the people while doing the project. Work will be divided according to our areas of expertise. If things exceed our knowledge, we should consult with a professional to ensure our project runs smoothly.[1]

References

[1] *ACM Code of Ethics and Professional Conduct*, ACM Code of Ethics 2.6, 2024. [Online]. Available: https://www.acm.org/code-of-ethics

[2] *ACM Code of Ethics and Professional Conduct*, ACM Code of Ethics 2.9, 2024. [Online]. Available: https://www.acm.org/code-of-ethics

[3] *IEEE Code of Ethics*, IEEE Code of Ethics 1, 2024. [Online]. Available: https://ieee-cas.org/about/ieee-code-ethics

[4] *Occupational Safety and Health Standards*. OSHA 1910.22, 2024. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.22

[5] *Occupational Safety and Health Standards.* OSHA 1910.132, 2024. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.132

[6] *Occupational Safety and Health Standards.* OSHA 1910.137, 2024. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.137

[7] *Occupational Safety and Health Standards.* OSHA 1910 Subpart E, 2024. [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910SubpartE