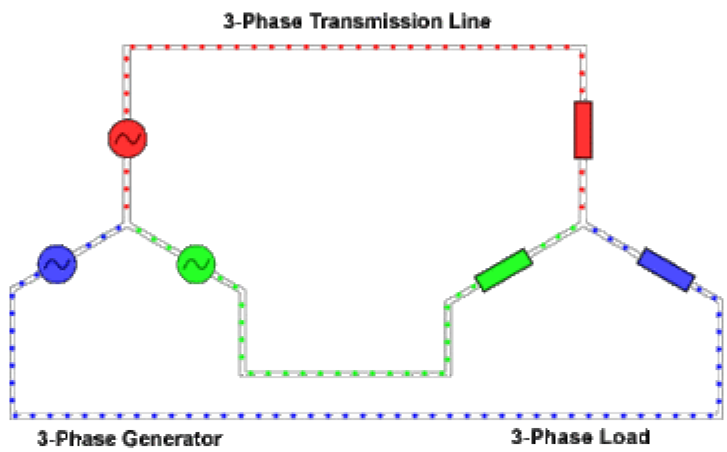
Proposal:
3-Phase AC Power Monitor



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Introduction

With the rise of Internet of Things, sensory devices are becoming mainstream in many household with many large amounts of data has become readily accessible for analytics. One particular set of data that this project explores is energy from 3-phase devices. 3-phase devices and power load are usually present in industry factories and offices which relies on high amount of power draws for operations. Our project aims to be the foundation toward 3-phase power analytics for optimizing industrial machinery and collect data for diagnosis of circuitry quality and harmonics and prognosis for the health of such devices by creating a low profile and low power 3-phase AC power monitor solution.

Project Specifications

Current polyphase energy meter solutions use a combination of a polyphase IC chip and a microprocessor. According to a Digi-Key article about polyphase energy meter designs, “polyphase energy meter designers needed to combine separate single-phase AFEs and add custom circuitry to measure phase dependent parameters”. A solution to multiple single-phase AFEs would be Analog Devices ADE9078 IC chip which solves issues like the “custom circuitry” and ensures the synchronization of multiple single-phase AFEs.

An issue with using microprocessors would be the data received from the IC chip would have to be processed quickly for real-time measurements. With instabilities from noise and harmonics from polyphase devices, the precision of phase measurement is also severely influenced by harmonic signal. According to an article that utilizes an FPGA for polyphase measurement system, the error from harmonics can be ignored when the Fast Fourier Transformation (FFT) algorithm is applied to measure the phase directly. However applying the FFT algorithm on a microprocessor sacrifices the real-time measurements of polyphase measurements. In order to solve these problems, the power phase processing system can be designed on FPGA parallel computation capabilities which can measure data from the ADE9078 chip and apply FFT algorithm simultaneously. With the combination of the high accuracy from a polyphase energy metering IC chip and the flexibility and fast computational power of an FPGA, which gives us functionality to have multiple real-time waveforms, noise detection/removal, and predictive analytics. This project aims to take multiple real-time measurements of functionalities such as harmonics, power, and voltage.

By the first quarter, our project is to create a solution using a polyphase IC chip (ADE9078) for measuring 3-phase measurements that uses the waveform sampling of the ADE9078 chip along with drivers for Arduino to validate the PCB board design. In the second quarter, we aim to transfer over the Arduino drivers over to an iCE40 FPGA board for parallel computation of reading, writing, and preprocessing data in a pipeline method to add additional functionalities to the 3-phase measuring systems.

Energy Metering IC Chip Choice

After looking at two common energy metering solutions for polyphase measurements (an array of single-phase IC chip versus a single polyphase IC chip), we compared them based on certain criterias necessary for our project such as support for Waveform Sampling Mode, accuracy, interface compatibility, and ease of use. Our group decided to use the ADE9078 as it met our specifications.

For ease of use, the ADE9078 guarantees synchronization of all of its channels compared to the array of single-phase IC chips method which requires complex circuitry to match the timing of data correctly. Another reason for using a polyphase IC chip is that this approach is more cost effective and would require less materials, but this can be an issue because a single polyphase IC chip can be difficult to repair as if a channel is broken on the polyphase chip, then the whole polyphase IC chip has to be replaced compared to the array of single-phase IC chip in which only a broken single-phase IC chip has to be replaced. However, in terms of ease of use, our group would still prefer a polyphase IC chip solution.

In terms of accuracy, ADE9078 IC chip is Analog Device's latest polyphase chip which is rated for Class 0.2 which meets the requirements for utility-grade metering.

As for compatibility, some other solutions use either SPI, I^2C, UART, or a proprietary interface. For our project we prioritize the SPI interface over the others as the SPI interface is simpler to use over other interfaces, consumes less power than I^2C, and allows for higher data rate and range.

We used three criteria (ease, accuracy, and interface) to choose a single polyphase IC chip over an array of single-phase IC chips because the polyphase IC chip, mainly the ADE9078, would require less complex circuit configuration, has high energy metering accuracy, and has simple interface as opposed to its other alternative, the array of single-phase IC chips, which has higher cost, requires syncing, and require extra interface ports to use with the processing board.

FPGA as the processing board choice over MCU or DSP cores

With the polyphase IC chip (ADE9078) allowing for the synchronization of all of its channel with up to Class 0.2 metering accuracy, it seems that a simple Microcontroller (MCU) would be enough for polyphase energy metering, but according to the ADE9078 datasheet, the waveform resampling mode "make it easy to perform harmonic analysis in an external processor that can use the 16-bit, 64 points per line cycle samples directly in a FFT". In order to create a polyphase energy metering solution that can also do harmonic analysis for industrial device quality assurance, we need the processing board to be able to apply Fast Fourier Transform (FFT) effectively. The reason why this alternate algorithm (FFT) is required for harmonic analysis is to compute the vector mathematics that uses multiple data from each voltage and current channels and analyze them at the same time.The algorithm would sample at the same interval of time producing N datasets. The speed is determined by how many operations the processor would have to compute. A microcontroller would have to perform N^2 operations with a normal Discrete Fourier Transform (DFT), even with modern computing power this would take a while for increasingly large values of N. The iCE40 chip however, can be programmed to only require N*log(N) operations if we implement the FFT algorithm. Microprocessors would struggle to apply a fast sampling algorithm while maintaining real-time measurements. In order to apply the FFT algorithm and maintain real-time measurement, the parallel computational power of an FPGA board is required. The FPGA that our project uses is the Lattice iCE40 board because it has built-in DSP capabilities such as, Sensor Fusion/Buffering which we need for pre-processing data. The low cost of the board would keep the cost down of the overall device we are trying to build. It's small form factor would allow the overall device to fit on a small area. In order for data to be available in real time, parallel computation is needed to avoid a delay in information. Since this board has dedicated DSP functions, it will make it easier to perform the sampling portion due to dedicated sections in its hardware.

The way the FPGA and microcontroller are built have a significant effect on where each one thrives and where they have their limitations. Unlike a microprocessor with fixed hardware, an FPGA's hardware can be reprogrammed for different tasks and standards, allowing us to work with custom standards and inputs To clarify, the FPGA board has dedicated sections of the chip devoted to writing, storing, preprocessing energy, metering data while being able to be reprogrammed for different AC voltage utility standards such as 208 to 480 AC voltage range, Wye and Delta configurations, Blondel and non-Blondel compliance, and metering specifications from IEEE or UL standards. Once we have the samples, we can then analyze them to determine how much power is being consumed from the powerlines. The data can also show abnormal spikes in usage which can alert the user to make sure the device connected is functioning properly or is used efficiently to not waste energy.

Project Schedule:

Quarter 1

Week	Progress/Upcoming activities
1 - 4	Research on 3-phase power delivery, review previous energy metering design
5 - 8	Week 5-6: Worked on Schematic Design + Review & edited feedback received by our advisor; Started look at Programming drivers compatible with Arduino Week 7: Worked on schematic optimization using LTSpice for resistors and light emitting diodes. Added fuse to LEDs to prevent shorting. Finished proposal (Fourth Draft) and continued unto fifth revision of the schematic. Poster outline created for Fall Review Session. Week 8: Start on the board design on Eagle. Work on finalizing the poster.
9 - 10	Week 9: Finish poster and create a BOM for the parts needed. Week 10: Order parts, finish board population, create a prototype and begin testing of the prototype.

Quarter 2:

Week	Activities
1 - 3	Update driver with additional functionalities
4 - 8	Make drivers compatible with FPGA iCE40 chip
9 - 10	Testing and validation

ITEMIZED INVENTORY OF PURCHASES:

Items	**Cost**
iCE40 FPGA board	$80
ADE9078 IC chip	$30
Custom PCB boards	$100
Misc. Electrical components	$220
Soldering materials	$70
Total	$500

References

Said, D M, and K M Nor. “Effects of Harmonics on Distribution Transformers.” IEEE Journals & Magazine - IEEE XPLORE, Wiley-IEEE Press, 10 Apr. 2009, https://ieeexplore.ieee.org/document/4813025

Digi-Keys North American Editors. “How to Simplify Design of a High-Accuracy Polyphase Energy Meter.” Digi-Key Electronics Corporation, 18 Apr. 2018, https://www.digikey.com/en/articles/techzone/2017/apr/how-to-simplify-design-high-accuracy-polyphase-energy-meter

Zhang X., Zhang Y., Lu X. (2012) Phase Measurement of Three-Phase Power Based on FPGA. In: Sénac P., Ott M., Seneviratne A. (eds) Wireless Communications and Applications. ICWCA 2011. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 72. Springer, Berlin, Heidelberg https://link.springer.com/chapter/10.1007/978-3-642-29157-9_16

Devices, Analog. “High Performance, Polyphase Energy Metering AFE.” ADE9078 Data Sheet *Analog*, Analog Devices Corporation, 2016, www.analog.com/media/en/technical-documentation/data-sheets/ADE9078.pdf.